BELL TELEPHONE QUARTERLY

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JULY, 1933

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AMERICAN TELEPHONE & TELEGRAPH CO.
NEW YORK

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A Medium of Suggestion and a Record of Progress

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The Telephone Fights an Earthquake

"NUMBER 108—your call to Seattle is ready.—Number 109—your call to Chicago is ready—" The loud-speaker boomed out the announcement. A man, a woman, pushed forward. They showed their numbered cards to the American Legion men holding back the crowd,—sometimes more than 500 people,—and were admitted to the front yard where temporary telephones were arrayed on tables. A few quick words over the emergency circuits and the anxiety of friends and relatives far away was allayed. There are people in the California earthquake zone who will not soon forget the open-air long distance telephone office that put them in touch with the outside world.

The cry of "tidal wave," fortunately unjustified, drove many to flee to the hills on that fatal Friday when much of Southern California quivered and shook. A family living across the street from the long distance telephone office in Long Beach gave permission, before they left, for the telephone company to use their yard. When they returned, they found tables on the porch, and shelves, benches, tables and telephones covering the whole front lawn. Here operators, sheltered by a canvas-covered framework, handled a deluge of calls. Perched high above the operators was a telephone man announcing through a loud-speaker the number and destination of each call as the connection was set up: "Number 116 —your call to Des Moines is ready,"—

An Ominous Rumble and Roar

It was late in the day of the 10th of this past March, 5:54 P.M. to be exact, that the earthquake struck,—unannounced, unanticipated and unaccompanied save by an ominous rumble and roar. Communities extending from Santa Barbara to

San Diego felt the temblor, although it was most severe in parts of Los Angeles and Orange Counties. Approximately 120 people lost their lives in the disaster, most of whom were pedestrians caught on the sidewalks by walls falling from poorly constructed buildings.

The shock was most pronounced in the vicinity of south Los Angeles, Compton, Long Beach and Santa Ana. The Bell System operates the exchanges in this area except for local service at Long Beach which is handled by the Associated Telephone Company, Ltd. Approximately 75,600 telephones were in the area seriously damaged by the earthquake.

Probably no other type of natural phenomenon produces greater nervousness and tendency towards hysteria than a sudden earthquake with no apparent warning. Only those who have experienced earthquakes can appreciate this and can fully realize how much courage it takes to stay at a switchboard or other post of duty during a severe earthquake.

Switchboard in Contortions

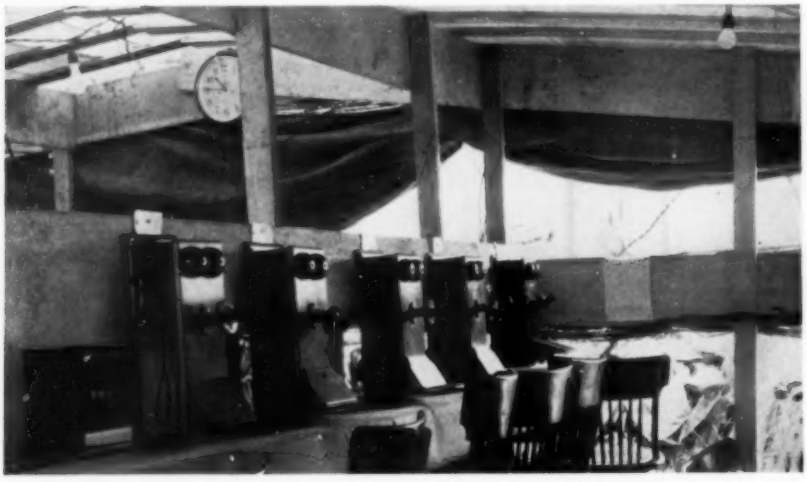
Loyalty to public service again came to the surface when the earthquake struck. At Long Beach, the Bell System long distance office was being operated by about twenty girls. All out-going calls from the city are handled by this center. When the shock came they stood back while the switchboard appeared to go into contortions. The lights went out for eighteen minutes, but the operators stuck to their posts handling calls for half an hour. Later they were directed to leave the building following subsequent shocks. Protests from the girls arose, but they finally left the board.

The Traffic Superintendent remained and completed some emergency calls received over the switchboard and from Long Beach city officials and others who came into the operating room to place calls. Emergency calls were put through for the police, hospitals, Army, Navy, Marines, the National Guard and to the press. At about 8:00 P.M. the operators

Temporary Telephone Service for the General Public Was Installed Across the Street from the Long Beach Toll Office. There were five hundred people around this installation the morning after the earthquake.

An American Legion Man Directing a Customer to the Telephone as It Was Announced through the Loud Speaker that His Long Distance Call Was Ready.

THE OUTDOOR TEMPORARY STRUCTURE AND SOME OF THE OPERATORS WHO WERE GIVING SERVICE AT LONG BEACH AFTER THE EARTHQUAKE.



ONE CORNER OF THE LONG BEACH OUTDOOR EMERGENCY TELEPHONE HEADQUARTERS EQUIPPED WITH SUBSCRIBER MAGNETO SETS THROUGH WHICH CALLS FROM THE STRICKEN AREA WERE PASSED BY OPERATORS TO THE LOS ANGELES LONG DISTANCE TERMINAL, THIRTY MILES AWAY.

again volunteered to go to work at the switchboard. At 8:45 P.M., following further shocks, they were directed again to leave. Newspaper reporters, policemen and a few other officials once more ventured into the shaking operating room, and several important calls were thus completed by using operators' telephone headsets.

"Get the Message Through"

In those first few hectic hours of the catastrophe no one knew the actual extent of damage done. Had telephone people known that the central office buildings had structurally withstood the jarring of continued shocks, and that not a single telephone employee on duty was to be seriously injured, they might have breathed more easily. But though they were ignorant of the extent of the disaster, there was no slackening in the drive to restore communication service within the stricken area and to the outside world. The courage and efficiency displayed by the operating, engineering, maintenance and transportation forces were everywhere in evidence.

Throughout Southern California, telephone people rushed voluntarily to headquarters to report for duty. This in itself took courage. Nobody knew what subsequent shocks, already in progress, might bring to their loved ones. Even former employees and operators visiting from Eastern States appeared at the central offices and volunteered their services. There were instances, too, of telephone company people reporting for duty despite injury to their relatives and demolition of their homes. Many employees were on duty forty-eight hours and more without rest. Both men and women refused to relinquish their posts.

At headquarters of the telephone company in Los Angeles, reports of the damage to buildings, equipment and plant were quickly gathered from the various districts. Urgent needs were cared for immediately and a co-ordinated plan of action

was developed by the heads of the departments for Long Beach, where the situation was most serious.

The building service personnel did great work in obtaining damage reports, clearing the operating rooms of debris, stopping the flow from broken water and gas connections. In a similar manner, the motor vehicle personnel rushed into the stricken districts, while they were still quaking, with emergency lighting units, drinking water, automobile storage batteries, lumber and food supplies. They later established a regular transportation schedule. Many of the operators at Compton and Long Beach depended entirely upon the company for drinking water and meals. Company commissaries were established at Compton, Long Beach and Santa Ana.

As the reports poured in, it was evident that the telephone system was affected, but that service to most Southern California points was not stopped and could not be stopped, even by a severe earthquake. Of telephone property, outside plant suffered the least damage, followed by equipment, then buildings. Considering the extent of the earthquake area, however, the damage was comparatively small.

Well-constructed Buildings Stand Up

The extent of damage to buildings in general in the earthquake area was considerably affected by the condition and type of soil of the building sites. Where there was a solid underlying formation of rock, gravel, or hard clay, there was less damage than in those cases where a deep subsoil of loose alluvium existed.

Buildings which had been well constructed upon modern and scientific lines structurally withstood the shocks and escaped with only minor damage. Steel and reinforced concrete construction, for example, suffered little damage, while many small buildings of inferior construction were wrecked. Standing out as examples of modern construction, the Bell System buildings distinguished themselves by withstanding the temblor

and resisting structural damage. Although the steel frame of the Lafayette building swayed, cracking walls and breaking partitions, neither the frame nor any of the steel connections were loosened or sprung by the movement. In the same manner, the reinforced concrete buildings at Santa Ana and Compton remained unweakened with no damage to the structural frame. The telephone company buildings of the small frame and stucco type, housing the unattended dial offices at Garden Grove and Placentia, both in the severely shaken area, were not damaged.

Damage to buildings which actually did occur, while often very serious and spectacular in nature, was limited to a small proportion of the structures in the affected area. In the case of telephone buildings, the Bell System long distance office building and the Associated Telephone Company's local exchange buildings in Long Beach were subjected to very severe shock. The Bell System building, upon which the telephone communication from the stricken area to the outside world depended, was badly shaken and in this case the engineers provided protection and bracing to ensure against any possible contingency.

In the post mortem of Los Angeles telephone building damage, it is of interest to note the difference between the effects of the shock on the Lafayette and Thornwall central office buildings, one located about three and one-half miles east of the other, and both placed with their longer dimensions on an east-west line. The north and south walls of the Lafayette building were affected the greatest by cracks, while the east and west walls of the Thornwall building suffered most. The earthquake movements were in varying directions in different sections of the area.

Telephone Equipment Severely Shaken

What happened to the central office equipment, particularly in the Los Angeles dial system offices, is another interesting

story. The heavy cabinets holding the line switchboards were jolted from six to eight inches out of line, but the equipment continued to function. Distributing frames and relay racks with their thousands of wires were ripped loose from their moorings in the concrete floors, yet the telephone circuits were not broken. The glass doors on the line switchboards were thrown open in places and the glass in some was shattered. Selector frames were thrown out of alignment in the Lafayette building. The slate fuse panels on nearly all of these frames were cracked at the corners where they are bolted to the frame uprights. Cable racks were bent or pulled out of line in two places where they were connected by a brace to a sidewall or a column. Marks on one column indicated there had been a lateral motion of approximately sixteen inches between the building column and the cable rack. In the Thornwall building, one cable rack was sheared loose from its support over a distance of about thirty feet.

In 1925, telephone engineers found central office storage batteries moved out of line and their connections broken after an earthquake in the Imperial Valley. Contemplating the possibility of a repetition of this trouble, an emergency battery support, to receive the batteries if shaken from their standard insulator supports, was designed and provided in most of the central offices. Following this earthquake, it was noted with satisfaction that the tons of storage batteries in two of the Southern California telephone buildings, shifting sidewise, had been caught and held by the supporting framework "just as they should," thus saving many sections from possible serious service interruptions in the great emergency.

In several locations where glass batteries were broken, serious service interruptions were avoided by the use of automobile batteries and emergency charging and lighting equipment.

Wires Vibrate Like Jumping-Ropes

Damage to outside plant was limited largely to that resulting from falling walls and the greater portion of the maintenance work was caused by crosses, short circuits and broken wires. Compton suffered more damage in this respect than any other exchange of the Southern California Telephone Company. The major business street was damaged to such an extent that practically all occupants moved their establishments into the Oil Exhibition Building at the north end of town, making it necessary to place about 1700 feet of cable to provide service. One section of 400-pair cable was destroyed by the falling walls of an adjacent building. In telephone lines, ordinarily taut, the poles nodded at each other and the wires vibrated like jumping-ropes during the first temblor.

Although there was no material damage experienced in the toll lines, it was necessary to clear many "crosses" and short circuits caused by swinging wires. In the Santa Ana-Newport Beach-Long Beach area, the lines had just been cleared when another shock repeated the trouble, making it necessary again to untangle the lines by climbing the poles and shaking the wires clear.

Some small amount of damage occurred in the underground plant due to displacement of cables.

Everybody Tries to Telephone at Once

The problem of handling an amount of telephone traffic even beyond the capacity of the equipment was almost as great as the problem of plant repair. Immediately following the earthquake the traffic load increased to several times its normal volume. This was in addition to the false signals created when receivers were knocked from hooks and open wires crossed and short-circuited. Fuses were blown by the overload in Los Angeles, Thornwall and Vermont offices, causing interruptions of short duration.

At Long Beach, the system of temporary facilities, referred

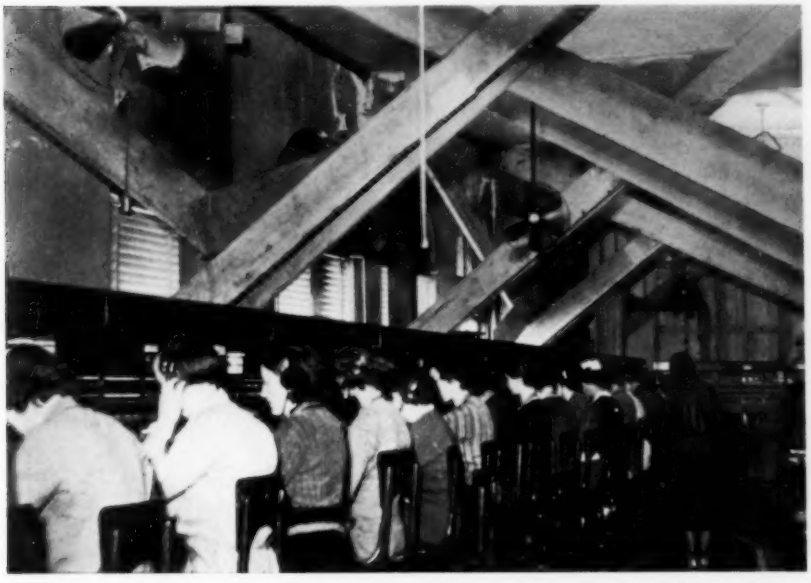
to at the beginning of this article, which was like that employed after the Santa Barbara earthquake some years ago, was placed in service at 7:00 A.M., on the day after the earthquake. By 11:00 A.M. all of the equipment available was in place and the traffic was moving with dispatch. About forty magneto type telephones were placed on shelves in the temporary structure. These were connected to Los Angeles toll circuits through a cable suspended from a tree, and were attended by toll operators. Connected in multiple with each of these telephones was a desk type instrument placed on a long shelf at the street curb for the use of patrons. Their calls were recorded at a counter across the front of the temporary office, and check numbers assigned to each call serially were given to the customer. Tickets were passed from the recorders to the line operators seated at the magneto telephones. When the called party was reached, or a report received, the operator notified a messenger who gave the information to the announcer.

Hundreds of calls went out from this point during the first day. For hours it was one of the focal spots in Long Beach.

Toll switchboard service was again started at 10:00 A.M. Saturday after the bracing of the telephone building was in place. With exception of the period between 12:00 and 1:00 P.M. when service was affected by false rumors of another impending earthquake and a tidal wave, the traffic flowed through in good order. The service through the outdoor temporary exchange was continued through Saturday, Sunday and Monday. The average business day messages originating in this office for the month of February, 1933, was 5,823. The messages completed through the regular and temporary offices following the earthquake compared as follows:

Saturday	2,383	(Day following earthquake)
Sunday	6,625	
Monday	10,254	
Tuesday	9,639	
Wednesday	8,640	
Thursday	8,397	

A Study in Bell System Building Construction. The three-story Santa Ana telephone building stood the earthquake with only minor damage while the automobile showroom across the street went crashing down.



"Business as Usual" in the Bell System Long Beach Office. These girls worked during the after-shocks in this room so braced that should another earthquake occur the walls could have collapsed and left the floors and ceilings of the three-story building intact.

Santa Ana Telephone Workers Lauded for Service During Quakes

Gratefully acknowledging many expressions of appreciation received by the Santa Ana telephone personnel for their service during the recent earthquake, E. S. Morrow, district manager of the Southern California Telephone company, today stated that no ... tions nor damages ... hem have resulted.

The story of w... the city's nerve ... quake came was ... telephone headqu... in the operating ... Dorothy Arnold, ... Mrs. Pea...

Telephone Girls Are Heroines of Tem...

Probably the real heroines of the ... earthquake were the 14 teleph... girls who remained at their ... hangs Friday evening at ...

N. Y. OPERATOR OFFERS HER AID HERE

Heroic Roles Played in Disaster

TELEPHONE CALLS DELUGE EXCHANGE

56 Operators Get 45,000 Calls in Four Hours of Quake Period

Weary telephone operators left ... ir positions at the exchange of ... Riverside office of the South... California Telephone company ... t night after having han... the abnormal unbelievable total ... 45,000 local and long dis... calls during the four-hour ... from 4 to 10 o'clock.

... id by District Manager M... ... first when the deluge of calls ... flooding the exchange after ... ial tremors of the disas... earthquake, a total of 56 op... worked feverishly during ... hour period to put River... communication with ... d relatives in the stricken ... with other persons in the ...

Paper Deluged

... s of the calls were re... answered by the Press... office where five trunks ... ery throughout the eve...

... of the immense volume ... lled by the Riverside ... ing the four-hour peri... ement ran the high... in figures obtaining ... andolph, wire ... ce, showing ... loud" to ... erage ... ed for the ... at 10. The ... operators ... Many volun... ry position ... exchange ... than the ...

Praise Given Local "Hello" Girls For Work

Balboa, Calif., March 11, 1933.
Editor Balboa Times:

You hear so many acts of heroism over radio regarding the terrible earthquake, it mentions among others, one regarding telephone operators at Long Beach ... to their posts. Now I ... like to call to your attention ... occurred right here in our ... mmunity which, no doubt, ... left untold unless you see ... blish the instance through ... table page of which I read ... ition.

... the quake was at ... ere were only two opera... duty at our telephone ex... Misses Helen Stephen... this Lindsay. They brave... by their guns thoug... ere in danger by fal... tion of buildin... rd almo...

Telephone Girls Do Valiant Service At Gardena Exchange While Earthquake Shakes Town

For an example of real courage ... nothing exceeds that of the tele... phone operators throughout the ... earthquake stricken zone of South... ern California and the Gardena ... change held up to the high ... itions of the service. Three ... girls, Erma Marty, Elizabeth ... ames and the chief operator, ... on Greenlund, were on duty at ... local exchange when the shock ... Friday evening. Not one left ... post. The telephone switch ... d suddenly be... with everyone ... with the build... knowing when ... office might ... s to their pos... hile the que... rons Fire Ch... e phone to ... o k so that ... alarms. A ... answered in ... ring him t... job and ev...

Within a few minutes, Miss ... ator re... Greenlund said, every o... ported back to duty w... the necessity of callin... the girls stuck to the ... them from 16 to 18 ... relief. All worked ... few stopped at ... came back again ... three hours of t...

The entire c... here on valiant ... Greenlund, ... Marty, Mary ...

PHONE GIRLS SHOW COURAGE

A dramatic story of coolness and ... courage is contained in the ... which more than a score ... telephone operators ... switchboards ... rocked ...

Phone Employees Do Splendid Work

Employees of the Southern Cali... nia Telephone Company again ... devotion to duty when ... the Southland ... ny met the ... style. Gen... ush issued a ... eporting ser... ns and told of ... lf-sacrifice of ... s of the organ...

Local Phone Girls Loyal to Their Company

The local corps of telephone op... ators in the Wilmington office ... ved their loyalty, ravery ... otion to duty at the ... earthquake. ... ed, ...

Tell of Race by Three Utilities To Serve Plan

In getting back into serv... within 24 hours after the ear... quake the management of ... News-Tribune and the Com... Printing Company extends ... congratulations and thank... the Southern California ... Company, the Southern C... Company, the Southern ... nia Telephone Company ... the Southern California ... The three ...

TELEPHONE GIRLS COMMAND NERVES AND SERVE PUBLIC

The two young women who ... stood the first wild panic follow... ing the earthquake at the local ... telephone office Friday evening ... were Miss Althea Irvine and Mrs. ... Thelma Locke.

With the building rocking and ... the phone board reeling and bang... ing, they stuck to the switchboard ... and answered all calls. The girls ... off duty reported at once and all ... were kept busy most of the night.

How difficult this was to do can ... easily be realized when few La... wita residents could remain in... doors but at every new shock rush... ed for the open in fear and trembl... ing. Others who served the com...

HEROISM CITED IN QUAKE AREA

Women are working as hard and ... as long as the men in relieving dis...

their posts' Heroic telephone operators at the LONG BEACH long distance office of the Southern California Telephone Co. took their places in the temporary structure erected when the exchange was temporarily abandoned and remained on duty for long hours so that quake victims could communicate with friends and relatives in other places.

... grams to help keep the minds of ... homeless off their troubles. Each ... night a giant campfire is built. A ... community sing is held. The Salva... tion Army band plays. Games are ... planned for the youngsters.

The marines and sailors have ... won the heart felt appreciation of ... townsfolk in the stricken districts. ... They are firm in keeping sightseers ... away from the wrecked buildings. ... But they are pleasant in perform... ance of their duty. They helps their ...

CALIFORNIA NEWSPAPERS PRAISE THE WORK OF THE TELEPHONE OPERATORS IN THE EMERGENCY

Another temporary toll office of eight stations, similar to that described for Long Beach was established in a lot adjacent to the Compton central office and many emergency calls were handled there.

Telephone Workers Earn Praise

Bell System wheels moving fast and Bell System minds in co-operative action were responsible for maintaining vital emergency service and many other valuable acts of public assistance rendered during the time of stress. The Associated Telephone Company people did valiant work in clearing the damage to their plant and service. No particular department of the telephone organization could be cited singly for loyalty and heroism. As this catastrophe has proven, it will take more than an earthquake to cripple for very long, or seriously, the service and spirit of the telephone family. That the many heroic deeds of the members of the organization were appreciated is evidenced by the tributes to operators, repairmen, supervisors and others, which immediately came from radio broadcasting stations, from the press, from individuals who received the service and from telephone company executives.

Under the heading "A Cheer for the Hello Girl," the *Los Angeles Record* said in part:

> Following the Long Beach earthquake there came the usual stories of heroism by telephone girls. It's an old story. Never was there a disaster yet that the girls didn't stick, through flood and fire, through danger and dread.
>
> Around Long Beach girls worked 48 hours at a stretch, in front of rocking switchboards, getting messages through. And all honor to them.

Editorial comment in the *Inglewood Californian* pointed out that

> There were many unsung heroines and heroes working silently and efficiently to keep telephone service as near normal as possible during one

of Southern California's most appalling emergencies—our recent earthquake visit.

More long distance calls were handled in Southern California during that Friday night and the next day than in any 24 hours in the history of the telephone company. It is creditable that so many were handled so efficiently.

Speaking of the telephone operators, the *Santa Ana Bulletin* said editorially:

While the city was tumbling down, these workers stayed at their posts and put through calls as rapidly as equipment would permit. They never faltered, even though the quakes continued to jostle them. It is nearly always the same in every disaster, the telephone girls stick to their jobs. They deserve the highest praise.

In like vein, the *Santa Ana Register* summed up the feeling of the public in the following editorial:

COMMUNITY GRATEFUL FOR TELEPHONE SERVICE

The telephone operators who remained at their posts, so that all through Friday night, while temblors continued to rock this section, calls were taken and put through wherever possible, are deserving of particular congratulation. For two types of calls the services of the operators were most appreciated. The first was the emergency calls for necessary aid, the second was the calls from individuals to those dear to them. Following the first shock, the principal thought in everyone's mind was to get in touch with those whose welfare is paramount in the mind and heart of the individual.

For a period Friday night, we were out of touch with a telephone, with the family scattered. It added immeasurably to our morale when we got back again where there was a telephone. The experience was undoubtedly multiplied a thousand-fold at that time. The community is appreciative of the telephone service throughout this crisis and congratulates the personnel upon which it depended.

It is costly wisdom that is bought by experience, but the knowledge that Southern California telephone people obtained from the earthquake may be valuable for the future. Southern California Bell System employees hope that their fellow

workers in other sections of the country will not have a repetition of these troubles of last March.

H. W. HITCHCOCK

(The author desires to emphasize the fact that while this paper was prepared under the supervision of the Engineering Department, it represents the combined effort of many individuals in many departments of the Company.)

Perfect Transmission and Reproduction of Symphonic Music in Auditory Perspective

Foreword

THE demonstration in Constitution Hall, Washington, on April 27th, of the perfect transmission and reproduction in full auditory perspective of a symphony concert produced in Philadelphia by the Philadelphia Orchestra and transmitted to Washington over underground telephone wires, marked the completion of several years' work by the research and engineering forces of the American Telephone and Telegraph Company and Bell Telephone Laboratories.

Sponsored by the National Academy of Sciences as a noteworthy scientific achievement and directed and controlled as to artistic and tonal effects by Dr. Leopold Stokowski, Director of the Philadelphia Orchestra, the transmitted program was listened to by a distinguished audience of musicians, scientists, musical critics and music lovers which filled the hall to capacity. The prolonged applause which followed each of the symphonic numbers and the several experiments made by Dr. Fletcher in demonstration of the capabilities of the system were proof of satisfactory accomplishment.

Not only did the concert demonstrate the possibility of perfect reproduction in full auditory perspective, but likewise the capability of the reproducing apparatus to give tonal effects far beyond the capability of any human orchestra. This was illustrated on the one hand in the pianissimo passages of "L'Après Midi d'un Faun" where the volume of sound was reduced to the very threshold of hearing without the introduction of any extraneous noise. At the other extreme the crashing

passages in the finale of Götterdämmerung were carried in loudness almost to the point where pain takes the place of hearing. In this latter number the lighting accompaniments which Electrical Research Products Incorporated had prepared for each number, to provide something pleasing for the eye, were particularly effective.

To accomplish the results obtained, multi-channel transmission was required. Actually three separate circuits were employed. Each circuit was capable of handling the entire frequency and volume range and each did in fact carry something of all that was produced. Because of the arrangement of pick-up microphones in Philadelphia and loudspeakers in Washington, most of the sound produced on the left-hand side of the stage in Philadelphia was transmitted over one circuit to a loudspeaker on the left-hand side of the stage in Washington. Similarly sounds produced in the center and on the right-hand side of the stage went mainly over separate circuits to properly placed loudspeakers in the center and right of the stage at Washington.

Each transmission circuit was capable of transmitting the entire range of frequencies from 40 to 15,000 cycles per second. Further the attenuation of all frequencies within this entire range, which is about three times the width of the bands used in radio broadcasting, had to be substantially the same; otherwise distortion would have been inevitable. Likewise each circuit had to be free from all electrical disturbances since their presence would have produced objectionable noise in the loudspeakers.

Thus while the wires used were those normally provided for telephone service, they had to be specially treated with frequency equalizing and noise preventing apparatus and with specially constructed and installed amplifiers.

The several pick-up microphones used at Philadelphia were designed to give a uniform flat response over the entire frequency and volume range. The power amplifiers employed at

Washington were designed not only to handle without distortion the full volume of energy required in fortissimo passages, but likewise the pianissimo passages without the introduction of noise. All of the power amplifiers were controlled by apparatus located in the conductor's box in the rear of Constitution Hall. These controls admitted of handling each channel separately or all together, as Dr. Stokowski elected. He was also provided with a talking circuit to Conductor Smallens in Philadelphia and a tempo circuit. Thus the whole performance was remotely controlled by a conductor in the rear of his audience and so in position to judge and regulate exactly the sounds to which they were listening.

Among the most extraordinary parts of the entire assemblage of apparatus were the loudspeakers. Like the microphones, lines, line and power amplifiers, they had to handle with complete fidelity the entire broad band of frequencies. Also they had to translate from electrical to sound energy, power which at times rose to as much as 150 watts per loudspeaker, and to distribute all sounds uniformly throughout the auditorium. The ordinary loudspeaker, such as is used in radio broadcast receivers, has a tendency to concentrate the higher frequencies in beams.

Since roughly half the energy of an orchestra is in the register below 300 cycles per second and half in the register from 300 to 15,000 cycles per second each loudspeaker was constructed of three separate units. One of these units was a large affair capable of handling all frequencies up to 300 cycles per second. The other two were identical and handled all frequencies above this point. Two units of this type were used to give a proper directional distribution of the higher frequencies. Division of the frequencies between the units of each type was accomplished by suitable band pass filters.

Technically the operation of the system in all its parts leaves little to be desired. Certain minor modifications, particularly with regard to refinement of the controls, are indicated and

considerable further work in the matter of making the several parts of the equipment suitable for regular use is required. It is certain, however, that a new instrument for the dissemination of high quality music and for the production of musical effects not hitherto attainable has been produced. How far it will be utilized is largely in the hands of the musical world. It would seem, however, that it should very greatly stimulate the development of symphonic orchestras since a widened audience should enlarge the support requisite for their maintenance.

F. B. JEWETT

PART I. THE DEMONSTRATION

Perfect reproduction of orchestral music with the illusion of hearing each separate instrument from its proper position on the stage, is now a practical accomplishment. The announcement on April 27, 1933, that a symphony concert played in Philadelphia had been so reproduced in a Washington auditorium attracted active interest, particularly among scientists and musicians. Reproduction of music by radio and in sound pictures is a commonplace of the day, and many people have become accustomed to these less than perfect reproductions. For many purposes such imperfect reproductions are quite satisfactory. The difference between a perfect and the more usual reproductions may be illustrated by a photographic analogy. A good photograph is a satisfactory record of a scene, but for a perfect reproduction, the true coloring would have to be portrayed, and the photograph would have to be taken so that it could be viewed through a stereoscope. Similar requirements must be met for perfect reproduction of music. Two of them, that both the complete frequency and complete volume ranges be transmitted, have been generally recognized for some time. The third, that the sounds must be reproduced with the correct auditory perspective, has been fully appreci-

ated only by those most closely associated with the science of sound reproduction.

Sounds in general are composed of a group of tones and over-tones ranging from the deep bass of the lowest organ notes, or those of a bass drum, to the shrillest tones the ear can hear. Each note of a musical instrument has a fundamental tone and a group of harmonics. The fundamental tone sets the pitch, and the harmonics give the note its quality. It is the harmonics that make it possible to distinguish a note on a violin from one on a trumpet or from any other of the same pitch. It is in the harmonics that reside much of the richness of music and the wealth of sensuous appeal. These tones and over-tones are known and recognized by their frequency, or vibratory rate; and the range of frequencies to which the ear responds runs from about 16 cycles per second to above 15,000 cycles for some ears. The sensitivity of the ear falls off rapidly at the higher frequencies, however, so that the effect of frequencies above 15,000 cycles is negligible for the most part. The highest note on the piano has a fundamental frequency of only about 4,000 cycles, and few of the musical instruments exceed this pitch, but the accompanying harmonics, or over-tones, which are of still higher frequencies, are very necessary to the proper quality and richness of the notes. Returning to the photographic analogy, reproducing music with only a part of the frequency range supplied is like supplying an ordinary photograph instead of one in colors.

Of no less importance, if the full aesthetic effect of music is to be obtained, is the range in volume. The ear has a recognizable range of volume as it has of frequency. This extends from sounds so weak that the ear can barely hear them, to sounds so intense that the sensation is one of pain rather than of hearing. For convenience in scientific study, the relative intensities of sounds are expressed in units known as decibels (abbreviated db), the threshold of hearing being taken as the reference base. On this scale the volume of sound one would

hear in a quiet garden, or an average whisper at a distance of four feet, are at a level of about 20 db, while the noise of a pneumatic riveter is at the 100 db level. The range of a large symphony orchestra is about 65 db,[1] so if the music of such an orchestra is to be faithfully transmitted electrically, a volume range of the order of 65 db must be transmitted: a range of power of three million to one. If the range is not correctly portrayed, the effect is similar to a photograph which has been incorrectly exposed and has very little contrast between the bright and dark portions.

The third requirement becomes of particular importance when the sound to be transmitted and reproduced is that from a large and relatively widely spaced group of instruments, such as a complete symphony orchestra. When one sits in an auditorium and listens to a symphony concert, he perceives the various sounds as originating at points spread over the considerable area of the stage. For lack of a better term, the effect may be called auditory perspective. Without it the music would be one dimensional and not expanded into its true spatial relationship. The difference may be compared to that between the appearance of a photograph of a scene and the same scene when viewed through a stereoscope. Experiments have shown that this effect is a highly necessary adjunct to perfect reproduction. No matter how faithfully the frequency and intensity ranges are reproduced, a large measure of color and depth is lacking if auditory perspective is missing.

How to obtain this auditory perspective in music transmitted and reproduced electrically was worked out by the scientists of Bell Telephone Laboratories as a result of their fundamental investigations in acoustics and telephonic transmission. During the course of those investigations they had developed telephonic systems of high quality, but for their further researches

[1] This range and other ranges given in this paper are on the basis of measurements made with the sound meter described in a paper by Castner, Dietze, Stanton and Tucker, April 1931, "Indicating Meter for Measurement and Analysis of Noise." Transactions of A. I. E. E., Sept. 1931.

they needed opportunity to utilize music in its more perfect forms. Now it happened that Dr. Leopold Stokowski, Director of the Philadelphia Orchestra, was interested in the possibilities of electrical systems for the production of exceptional orchestral effects. Through his voluntary co-operation, therefore, the Laboratories' scientists were able to make quantitative physical studies of music as rendered by his orchestra, and so to perfect their designs; and with the completion of the new equipment some of the possibilities which Dr. Stokowski had hoped for became practicable. An extended series of tests was then carried on in Philadelphia in which the Laboratories' scientists were generously assisted by Dr. Stokowski. As a result of these studies, it was found that by employing two microphones, one properly located on each side of the orchestra stage, and by transmitting over two separate circuits to two of the newly developed loud speakers placed at opposite sides of the listening stage, the illusion of actual presence of the orchestra could be satisfactorily produced. The addition of a third system, with microphone and loud speaker located centrally on the stages, enhanced the realism to some extent, particularly for certain sections of the auditorium.

Even with the discovery of a comparatively simple means of obtaining true auditory perspective, the problem was not completely solved. Never before had either the complete frequency, or the complete volume range, of a symphony orchestra been commercially transmitted and reproduced. There was available no complete chain of apparatus, from microphone to loud speaker that would faithfully transmit the entire range of frequency and volume. Microphones offered the fewest difficulties. Bell Laboratories had already designed sensitive microphones that would transmit practically the entire range required, and only minor modifications were needed to make them entirely suitable.

This was not true of the amplifiers. There had to be developed amplifiers which would faithfully transmit all frequenc-

ies from 40 to 15,000 cycles at levels from the barely audible pianissimo effects to the resounding orchestral crashes of three million times greater power; and all the pieces of apparatus had to be so designed that even during intervals of complete silence not the slightest noise would be introduced to suggest the presence of electrical apparatus. No underlying hum or noise such as is commonly present in other systems of reproduction, could be tolerated with the new apparatus. In the intervals of silence there must be real silence: a dead auditory void in which the fall of a pin could be heard. This has actually been accomplished to a degree heretofore unknown with amplifiers operated entirely on alternating current. When audience and orchestra were at their quietest, no noise was added by the transmission system.

Of even greater difficulty, possibly, was the design of suitable loud speakers. It is not practicable to obtain the entire frequency range with a single unit, and so two types of loud speakers are used. One is employed for the frequencies from 40 to 300 cycles; and another type, for the range from 300 to 15,000 cycles. These loud speakers are different from anything previously produced commercially. Never before have these elements fulfilled such difficult requirements of frequency range and volume or converted so much of the electrical energy into sound power. The best present sound picture systems record and reproduce approximately half the range of frequencies handled by the new loud speakers. In volume range the comparison is equally remarkable. Sound picture systems under the most favorable conditions may provide a volume range of 40 to 45 db, corresponding to a power range of 10,000–30,000 to 1. The range provided by the new apparatus is 80 db, corresponding to a power range of 100,000,000 to 1.

The new loud speakers and their associated equipment of amplifiers and microphones are, therefore, fully capable of handling the entire volume range of a symphony orchestra. When one speaks of range of loudness which can be handled

by an electrical system for reproduction, one is concerned with the differences between the loudest and faintest passages of the music which it can reproduce. There is in addition the problem of handling the peaks of maximum loudness. These peaks in the case of music from a symphony orchestra are beyond the possibilities of the ordinary system to reproduce without distortions which seriously affect the musical sonority. The low frequency sounds make the largest contribution to the peaks of sound power which must be handled to meet these conditions. The diaphragm of the low frequency element in the new loud speaker has been made nearly seven times larger than that of the elements used ordinarily for sound picture reproduction. By these diaphragms a large column of air is set into motion.

The ordinary loud speaker also becomes directional in its characteristics at the higher frequencies. Low frequency sounds spread in all directions from the mouth of the horn, but the higher frequencies tend to concentrate into a beam projected directly ahead of the horn; and the width of the beam becomes narrower and narrower as the frequency increases. Because of this fact, the audience in a large hall equipped with the ordinary loud speakers, never hear quite the proper blending of frequencies. Those directly in front of the horn receive too great a proportion of the higher frequencies, while those on the sides receive too much of the low frequencies. To avoid this effect, the horn of each high-frequency element is divided into 16 diverging rectangular sections which spread the sound over an arc of 60 degrees vertically and one of 60 degrees horizontally. Two of these units placed side by side thus spread the sound over a horizontal angle of 120 degrees—a far wider coverage than has been obtained before and one which distributes the sound throughout the auditorium with a faithful blending of the frequencies.

Besides providing for the full volume range of the orchestra, the amplifiers and loud speakers have an additional power

capacity of at least 10 db, so that, if desired, the volume of loud passages may be made ten times as great as the actual output of the orchestra. Technically described, the maximum sound power of a symphony orchestra integrated over an interval of two-tenths of a second is less than 20 watts, whereas that possible from the loud speakers of the new apparatus is more than 200 watts. This additional capacity allows effects to be obtained which have been impossible before. Besides the effects of range and quality of tone, the total aesthetic appeal of an orchestra is due in no small degree to the range in volume. The number of musicians one can place on a stage is limited. To increase the size of a modern symphony orchestra by ten times is impossible in any existing hall. Since it is relatively simple to place the amplification control before the director, however, the new apparatus enables the director to secure at will the equivalent of an orchestra of nearly a thousand musicians, or to reduce the volume to any desired degree. He is thus able to produce sounds louder than the orchestra alone, or to make faint sounds even fainter than the performers play them, or to change the rate at which crescendos build up and diminuendos die away.

The advantage of this control of volume does not end here, however. Its presence makes it possible to reproduce operatic music, where a soloist is accompanied by an orchestra, without allowing the voice of the singer to be drowned out by the louder orchestral passages. For this purpose another channel, including its separate microphone, transmission line and loud speaker, can be provided primarily for the singer. The volume of output of this channel is controllable independently of the others. In this way the loudness of the voice may always be kept above that of the orchestra and the desired musical effect be obtained, with the singer able to concentrate upon the beauty rather than the loudness of the voice.

It is also practicable to introduce quality as well as volume control into the circuit to be used by the director. In this way

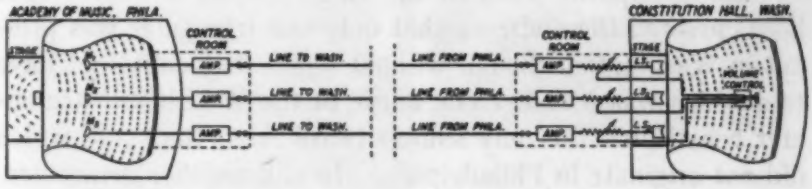
he can regulate the bass or overtone content of the music independently of the loudness to a much more marked degree than is possible with the instruments themselves. There thus reside in the new apparatus possibilities heretofore unattainable; and telephonic research has laid a foundation for what may be an important advance in musical aesthetics.

The first public demonstration of the new apparatus was given in Washington on the evening of April 27, 1933 under the auspices of the National Academy of Sciences. At that time Dr. Stokowski, Director of the Philadelphia Orchestra, manipulated the controls from a box in the rear of Constitution Hall, while the Philadelphia Orchestra, led by Associate Conductor Alexander Smallens, played in the Academy of Music at Philadelphia. Between Philadelphia and Washington, the music was transmitted over telephone cable circuits. The program consisted of the Toccata and Fugue in D Minor, of Bach; Beethoven's Symphony No. 5 in C Minor; L'Après-midi d'un Faun of Debussy; and the Finale of Götterdämmerung, with Miss Agnes Davis as Brünhilde. A visual accompaniment was provided for the music by Electrical Research Products, Incorporated. Its stage direction—through the courtesy of the Yale School of Drama—was by S. R. McCandless, and the designs were by Eugene Savage and George Davidson.

For this demonstration three circuits were used, left, center, and right. Except for the "Götterdämerung" music the three channels, on a common volume control, were all used for reproducing the orchestra. For the solo passages of "Götterdämerung," Miss Davis as Brünhilde sang into a special microphone which picked up her voice but very little of the orchestra music, and the center channel was then used with a separate volume control to reproduce her voice in such a way that it always dominated the orchestra. Mr. Stokowski had before him the volume controls, a set of quality controls by means of which he could increase or decrease bass or overtones at will, a microphone through which he could talk to the orchestra,

when they were not playing, and a signal system for communication with Mr. Smallens during the renditions. By means of this microphone circuit the orchestra in Philadelphia could also hear the hearty applause of the Washington audience and were given a direct indication of the appreciation of their efforts. The details of the complex line circuits supplying these arrangements are presented by Mr. H. S. Hamilton in Part II of this paper.

LOUD SPEAKER ARRANGEMENT



Dr. W. W. Campbell, President of the National Academy of Sciences, introduced Dr. Harvey Fletcher, Director of Acoustical Research at Bell Telephone Laboratories. With the assistance of engineers and members of the orchestra in Philadelphia, Dr. Fletcher then performed several experiments to demonstrate the important characteristics of the new apparatus. The first set of experiments demonstrated auditory perspective. On a small stage at the Academy of Music in Philadelphia, where the pickup microphones were installed, a workman busily constructing a box with hammer and saw was receiving suggestions and comments from a fellow workman in the right wing. All the speech and accompanying sounds were transmitted over cable circuits to the loud speakers on the stage of Constitution Hall in Washington. So realistic was the effect that to the audience the act seemed to be taking place on the stage before them. Not only were the sounds of sawing, hammering and talking faithfully reproduced, but the correct auditory perspective enabled the listeners to place each sound

in its proper position, and to follow the movements of the actors by their footsteps and voices.

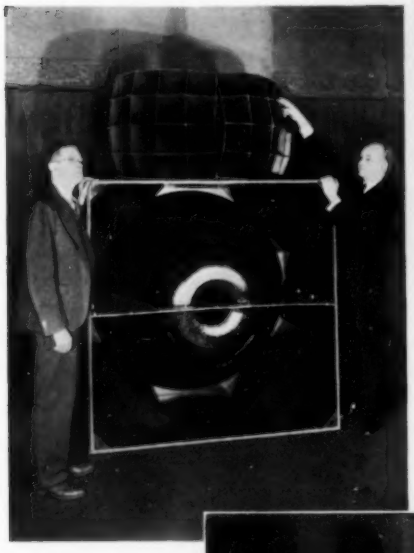
For another demonstration, the audience heard a soprano sing "Coming Through the Rye" as she walked back and forth on the stage in Philadelphia. Here again her voice was reproduced in Washington with such exact auditory perspective that the singer appeared to be strolling on the stage of Constitution Hall.

In one experiment a trumpeter in Washington and one in Philadelphia played alternately at stage center, and then walked to opposite sides of the stage to play a duet. Spot lights assured the audience that only one trumpeter was present in Washington, though without lights they could not have told which was which. The music of the Washington trumpeter constituted the only sounds heard from the stage which did not originate in Philadelphia. In still another demonstration sounds of a bell and tambourine flitted about the stage, high overhead as well as from side to side.

To show the volume range possible with the new equipment, the orchestra played a selection at a constant level of loudness, while the output of the loud speakers was varied from a level so low that the instruments could scarcely be heard, up to a loudness almost great enough to be painful. Throughout the whole range, the reproduction was faithful in all respects except the level of loudness; there was no appreciable distortion or noise to mar the perfection of the reproduction, and the wide range in volume was vividly impressed on the audience.

The effect of limiting the range in pitch, or frequency, was illustrated by employing electric filters to cut out one octave at a time—first from the upper end of the range and then from the lower. The new apparatus reproduces faithfully about 9 octaves or from 40 to 15,000 cycles, compared to about six for ordinary radio reproduction. As a preliminary experiment an oscillator in Philadelphia transmitted over the line and through the system frequencies continuously varying from

(Right) R. J. Tillman of the American Telephone and Telegraph Company, Left, and A. R. Soffel of Bell Telephone Laboratories, Right, at the Voltage Amplifiers in Constitution Hall, Washington, D. C.



(Left) E. C. Wente, Left, and A. L. Thuras, Right, of Bell Telephone Laboratories, Discussing the Distribution Obtained from the High Frequency Loud Speakers Used for the Frequency Range 300 to 15,000 Cycles. Lower frequencies were radiated by the large unit on the floor.

(Right) Control Equipment Used by Mr. Stokowski; on the Right the Quality Control, Volume Control Center, and Switching Box at Left. The right hand dial controlled the orchestra channels, the left hand the solo channel when used. The first two keys at right of switching box were the tempo signal and orchestra stop-play signal respectively. Communication with the orchestra was obtained through the microphone on the volume control box.

(Above) THE CONTROL ROOM IN THE BASEMENT OF THE PHILADELPHIA ACADEMY OF MUSIC. W. A. Munson of the Bell Telephone Laboratories measuring power level sent to Washington and R. L. Snyder of the Bell Telephone Company of Pennsylvania talking on the order wire. At the left are the power amplifiers and at the right switching apparatus used in the demonstrations.

(Right) D. T. BELL OF BELL TELEPHONE LABORATORIES, AT THE POWER AMPLIFIERS IN CONSTITUTION HALL, WASHINGTON, D. C.

40 cycles to 15,000 cycles. The frequency of the tone was indicated by a line moving across a large chart showing a musical scale extended to accommodate this wide range. Then the effects of eliminating high and low frequencies from both a fife and drum duet and from the music of the orchestra were presented. By this demonstration the audience had the opportunity of judging the importance of the complete range to the full aesthetic appeal of music, and of comparing it with the more limited ranges ordinarily heard with other methods of reproduction.

The technical features of these new developments, which were carried on as part of the research program of the American Telephone and Telegraph Company, were disclosed for the first time by Dr. F. B. Jewett, Vice President of the American Telephone and Telegraph Company in charge of development and research, at a meeting of the National Academy of Sciences on Tuesday afternoon of April 25th. In discussing the future of the new system, Dr. Jewett said in part:

"As to the future of the accomplishment shown here today, it is difficult to make any definite prediction. What we have done is to produce pickup microphones, amplifiers, electrical filters, transmission lines and loud-speaking reproducers so perfect that the entire frequency and volume range of the most exacting orchestral and vocal music can be reproduced at a distance without impairment of quality. We have also worked out the arrangements by which substantially perfect auditory perspective is possible. This latter is an essential part of the problem if realistic illusion as to the physical arrangement of the component parts of an orchestra is desired.

"We can place at the disposal of the musical director instrumentalities which will enable him to produce at a distant point, or at many distant points simultaneously, a completely faithful replica of the tonal effects produced locally in the auditorium on the stage of which the orchestra is performing. Likewise, portions of this same equipment place at his disposal

the means of very greatly extending the range of orchestral reproduction and of making possible artistic effects hitherto unattainable.

"With these instrumentalities available, the questions of the manner and extent of their use are primarily questions for the musician and those interested in music rather than for the physicist and the engineer. Our job has been to produce a set of tools. The musicians and musical directors, and back of them the musical composers, must determine just how these tools can best be used and what they can best produce. By its very nature the ensemble of what we have created is primarily of value for musical production or reproduction in halls, theatres or auditoriums. In a word, its field of applicability is where a large number of people might congregate for the common enjoyment of music of distinction. In its present form it is not directly applicable to the limited environment of the home.

"These new tools offer not only an enlarged field of possibility to the musician and the composer for the production of auditory effects, but likewise a great broadening of the audience which derives pleasure from such effects. Many people, especially in our smaller cities, are now deprived of the ability to hear good orchestral music by the factors of cost and distance, and the element of time in going to the cities where orchestral music is normally produced. What we as physicists and engineers have done is to provide a mechanism for obviating these factors. Whether the results justify our expections is for others to say."

W. B. Snow

Part II. Transmission

The transmission of orchestral music to distant points for reproduction with the perfection described by Mr. Snow in Part I of this article requires that the transmission channels be of such a character as not to limit the performance of the

new reproducing system either in frequency range or volume range, or by the introduction of other forms of distortion. High grade circuits for the transmission of music are not, of course, new in the Bell System. Our better grade program circuits are capable of transmitting a frequency band from 40 to 8,000 cycles and a volume range of the order of 45 db for a length of 1,000 miles, which volume range corresponds to a power ratio of 25,000 to 1. This performance is more than adequate for present day chain broadcasting. The new circuits must, however, transmit a frequency band nearly twice as wide and a volume range more than 30 db greater than for the 1,000-mile program circuit. This greater volume range represents an increase in power ratio several thousand fold.

Although transmission at audio and carrier frequencies were both considered in the preliminary studies, the interference and distortion requirements as well as the general trend of recent development, indicated that carrier transmission was preferable, at least over the major part of the path. Non-loaded program pairs were available in one of the cables between Philadelphia and Washington. In this cable as well as in the other cables on this route carrier was not used. By employing carrier for the new channels, therefore, there would be no cross-talk interference from other pairs in the cable, since the lowest carrier frequency would be above the highest audio-frequency.

The choice of carrier, and the particular value of carrier frequency selected, were also influenced by a survey of the sources of outside interference which might affect the quietness of the circuits between the terminal cities. Several such sources were found, but the highest had a frequency of 22,000 cycles. By choosing a carrier of 40,000 cycles, therefore, and transmitting the lower side band, 25,000 to 40,000 cycles, outside interference could be minimized. Because facilities for the operation of carrier apparatus, such as adequate power supplies, were available at the toll offices in Philadelphia and Washington, the carrier channels were terminated at these two

points. Between the toll offices in the two cities and the Academy of Music in Philadelphia and Constitution Hall in Washington, audio-frequency transmission was employed. These distances were short enough so that neither crosstalk nor noise arising in them was of much consequence.

The actual route of the cable is shown in the accompanying illustration. Regular telephone repeater stations are located at Philadelphia, Elkton, Baltimore and Washington. Because of the large attenuation at the high carrier frequencies, however, three additional intermediate amplifier stations were

established at Holly Oak, Abingdon and Laurel. At Holly Oak the amplifiers were housed in an existing telephone office, but at Abingdon and Laurel small temporary structures were erected which were just large enough to house the equipment and to permit an attendant to be stationed there during the demonstration. The structure at Abingdon was of welded steel and is shown in Figures 1 and 2.

All of the carrier amplifiers, both at the two terminals and at the intermediate stations, were especially designed both to be unusually free from distortion or non-linearity, and to be very stable with respect to variations in power supply. Except at the Philadelphia terminal, equalizers, associated with all the amplifiers, were employed to compensate for the difference in attenuation at the various frequencies, so that the output of the amplifiers would be at the same level for all frequencies. Although the gain introduced at each amplifier station at the higher frequencies was about 50 db, correspond-

FIGURE 1. THE TEMPORARY AMPLIFIER STATION AT ABINGDON WAS A SMALL WELDED STEEL STRUCTURE OF INEXPENSIVE YET RUGGED CONSTRUCTION.

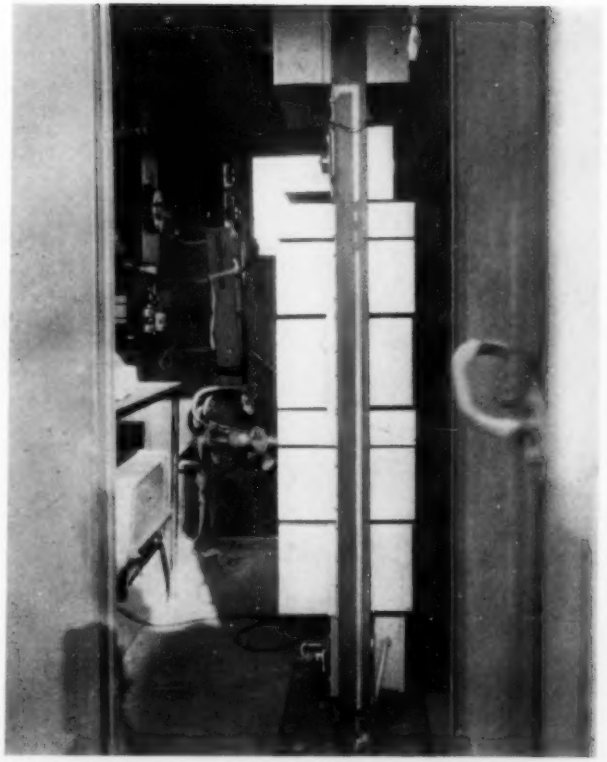


FIGURE 2. WITHIN THE ABINGDON AMPLIFIER STATION WAS A SINGLE BAY CARRYING THE AMPLIFIERS, EQUALIZERS, AND ACCESSORY EQUIPMENT AND MAINTENANCE FACILITIES TO PERMIT EMERGENCY REPAIRS AND ADJUSTMENTS.

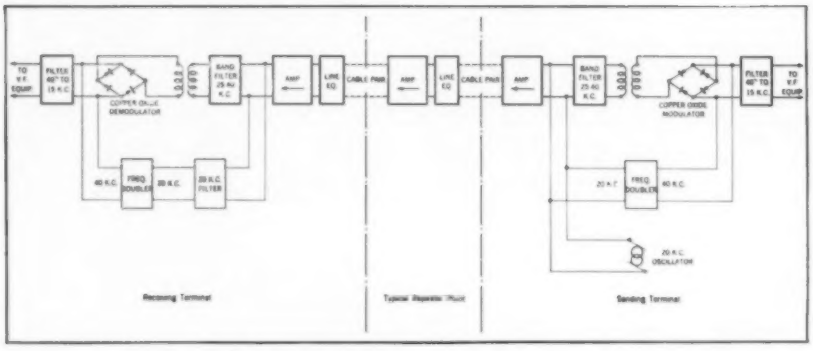


FIGURE 3. SIMPLIFIED SCHEMATIC OF A SINGLE CHANNEL FOR THE PHILADELPHIA-WASHINGTON DEMONSTRATION.

FIGURE 4. TOLL TERMINAL EQUIPMENT AT WASHINGTON.

ing to a power amplification of 100,000 times, the overall characteristic of the lines—from the Academy of Music to Constitution Hall—was flat to within ± 1 db over the entire frequency range from 40 to 15,000 cycles. Due to the employment of very stable amplifiers and underground cables which were not subject to rapid changes in temperature, the transmission variation over the entire frequency band did not vary more than a few tenths of a db from day to day.

Amplifiers and equalizers are required for the short audio-frequency circuits at each end, as well as for the carrier circuits. Existing apparatus was employed, although modified slightly to meet the unusual conditions of the Philadelphia-Washington demonstration. At Philadelphia both amplifier and equalizer for the audio-section were located in the Philadelphia toll office, but in Washington, the amplifier was at the toll office, and the equalizer in Constitution Hall.

The carrier system employed differed from those ordinarily used in that it incorporated "vestigial" side band transmission. In carrier systems for ordinary speech transmission, the transmitted band extends approximately from 200 to 2,700 cycles. If a carrier of 40,000 cycles were to be used for voice transmission, and the lower side band transmitted, the voice frequencies would be allowed to modulate the carrier and thereby produce the usual sum and difference frequencies. There would thus result a band of frequencies from 37,300 to 39,800 cycles and another from 40,200 to 42,700 cycles. The separation of 400 cycles between the highest frequency of the lower side band and the lowest frequency of the upper side band is sufficient to allow the filters to introduce enough loss so that practically none of the upper side band is transmitted. The carrier is substantially balanced out in the modulator.

For the Philadelphia-Washington demonstration, however, the frequency band was from 40 to 15,000 cycles, and as a result the lower side band extended from 25,000 to 39,960 cycles. Between this highest frequency of the lower side band

and the lowest frequency of the upper side band is a band of only 80 cycles. The provision of a filter which would have the necessary discrimination in this narrow band against the unwanted side band presented a rather severe filter design problem. Instead of attempting to provide a filter of that kind, a filter of considerably less sharp discrimination was employed which allowed some of the unwanted (upper) side band to pass. By careful attention to phase relations between the wanted side band and the portion of the unwanted side band that was transmitted the combined result at the receiving end was the same as if the entire lower side band was transmitted without any of the upper.

This type of transmission requires very accurate control of the phase relationship between the carrier frequency supplied to the modulator at the sending end and that supplied to the demodulator at the receiving end. This was accomplished by transmitting a special control frequency of 20,000 cycles over each circuit along with the music band. At each end of the line frequency doublers are employed to obtain 40,000 cycles for modulating and demodulating. The general arrangement of the carrier portion of the circuit is shown in Figure 3.

As already noted, one of the most difficult requirements to be met was the wide volume range that had to be transmitted. In general, the volume range a system can transmit is limited by the maximum power the amplifiers can handle without distortion, and the minimum level to which the signals may be allowed to drop without being interfered with by noise. This noise may be introduced either through the cable sheath from outside sources, or from other conductors within the cable. One of the advantages of using the higher carrier frequencies is that the sheath of the cable acts as a more effective shield. Because of this fact, and of the placement of the frequency band already discussed, no special precautions had to be taken to decrease outside interference.

The situation regarding noise introduced from other pairs in the same cable was not quite so satisfactory. There was, however, no appreciable source of noise at any point except Baltimore. Here the level of the incoming signals was so low that certain high frequency noises produced in the office, entered the cable on the other pairs and caused interference. To eliminate this, choke coils were introduced in all pairs of the cable but those used for the music transmission. These coils were not inductive to ordinary telephone and telegraph currents but were inductive to currents flowing over the conductors to ground, thus reducing these currents and minimizing their interference with the music.

To assist further in transmitting the desired volume range, the method of predistortion was resorted to. In music the energy content of the higher frequencies is materially less than that of the lower, so that if they were sent out over the line at their true levels, line attenuation would much sooner reduce them to levels where noise interference becomes of importance. By increasing the level of the frequencies above 1,000 cycles relative to the frequencies below 1,000 cycles, however, this is avoided, and no overloading of the amplifiers results because after the higher frequencies have been increased, they still have no greater energy content than the lower. At the receiving end the proper amplitude relationship between high and low frequencies is restored by networks which decrease the levels of the higher frequencies by the same amount they were increased by the predistortion. By these various means a volume range of the order of 80 db is realized without either overloading the amplifiers or introducing noise.

As discussed in the accompanying paper referred to, three separate channels were employed for the demonstration, and for these channels three non-loaded program pairs of one cable were used. Three additional non-loaded pairs were provided as spares, and were arranged so they could be patched in at any repeater station in place of the regular pairs. Two additional

transmission channels were set up which were in a different cable all the way from Philadelphia to Washington. These two circuits were taken from the regular program circuit layout and were operated on an audio-frequency basis throughout. Minor readjustments were made on these circuits so that for the moderate distance involved they would transmit a frequency range from 40 to 9,000 cycles and a volume range of about 60 db. At the two terminals they were arranged through switching devices so that either or both could be instantly substituted for the channels they were designed to protect. Had it been necessary to utilize these emergency channels, a very creditable performance could have been given although some slight impairment might have been detected.

In addition to these main and emergency circuits for transmitting the music, others were set up for signaling and supervisory purposes. A talking circuit was extended from a microphone in the control box at Constitution Hall to a loudspeaker on the stage of the Academy of Music so that Mr. Stokowski at Washington could talk to Associate Conductor Smallens at Philadelphia. This circuit was also connected to loudspeakers in the control rooms at the two terminals to enable the operators to follow more easily the continuity of the performance. Two signal circuits under the control of Mr. Stokowski were also established between the same points. Over one he signaled to start and stop the orchestra, and this circuit was associated with a switching mechanism which cut out the loudspeaker at the Academy of Music when the orchestra was playing. This was necessary to avoid "singing" around the circuit consisting of the main channels and the "Stokowski" talking channel. The other circuit was to signal the tempo for various passages in each selection. This was necessary because the talking circuit was interrupted while the orchestra was playing.

Besides these various signaling and talking circuits, two order wire circuits were provided. One enabled the men at all repeater points to be in communication with the control

office in Washington, and the other served as a communication channel between the operators at Constitution Hall and the Academy of Music.

The terminal equipment at Washington was set up on six bays. The installation is shown in Figure 4. At the extreme left is the bay containing the carrier amplifiers and their associated equalizers for the three line circuits. The carrier terminal equipment, consisting of demodulators, band pass filters, etc., is mounted one bay per channel. Two bays are shown in the photograph, the third bay being temporarily located at Philadelphia when the photograph was taken. The two bays in the foreground include amplifiers, jacks, volume indicators, and other equipment associated with the audio-frequency portion of the lines.

The severe requirements for this new type of service not only necessitated the most careful design of all the component parts, but required many weeks of testing before the final demonstration. For one series of tests a circuit was set up from Philadelphia to Baltimore and back over which music was transmitted from the stage in the Academy of Music to loud-speakers set up in the foyer. The reproduction of music transmitted both over this 200-mile loop and over an equivalent distortionless network was then listened to successively. No difference in quality was detectable. Although a considerable amount of time was spent in developing and perfecting the apparatus and arrangements for this first demonstration, the designs made and experience gained will greatly facilitate the establishment of similar circuits elsewhere as occasion warrants.

H. S. HAMILTON

The Talking Efficiency of Telephone Circuits

WHEN in 1876, Dom Pedro, Emperor of Brazil, attracted by his friendship for Alexander Graham Bell to a modest exhibit at the Centennial Exposition, placed the crude model of Bell's electrical speaking telegraph to his ear, he uttered that historic exclamation, "My God! It talks!" His amazement was not clouded by any question of quantitative measurement of this marvelous phenomenon, of expressing by some number just how well the instrument talked, nor of determining how its performance could be measured or computed. It was sufficient that this little scientific toy actually reproduced the human voice.

This is typical of the first stage in the development of a new application of science. But when the marvel that it works at all becomes a commonplace, and the invention passes from the stage of a scientific toy into that of commercial application, there quickly develops a desire to measure and to express its performance in quantitative terms. Very soon the question is asked, "How well does the device perform in this case and in that?" As efforts are concentrated on improvements so that the new device may give better service to the customers, the need becomes constantly more apparent for methods of quantitative measurements to express as accurately as possible the degree of satisfaction given to the customer. Standards of performance to be met under various conditions are established and the actual performance of the product is compared with these standards. The degree of improvement in performance resulting from further perfections is expressed quantitatively and the way is laid for comparing the relative performance and costs resulting from different designs or methods.

Sometimes this measurement of performance is very complicated. How, for example, can one express in terms of a single figure the technical performance of a motor car? In the past, much weight was often given to the miles per gallon of gasoline; but how many today buy cars on that basis? Apart from questions of economy, a comprehensive measurement of performance must take into consideration acceleration and braking, speed, riding qualities, turning radius, ease of control, and freedom from breakdowns or repairs. Also the variation in these qualities with the age of the car is a factor.

Electrical Efficiency Used to Measure Transmission

When methods for the quantitative measurement of the relative talking efficiencies of telephone circuits were first being developed, circuits were compared on the basis of the loudness of the sounds received over them. It is true that even then there were other factors influencing the talking efficiency. However, methods were lacking for measuring these influences in the early days, and in fact the loudness of received sounds was by far the most important factor in comparing the relative performance of different circuits. It was natural then that the first quantitative comparisons were made by selecting a typical telephone circuit as a standard and adjusting the length of circuit until it gave the same loudness as the circuit under test. This led to the first quantitative scale, the number of miles of cable in the standard circuit, when so adjusted, being used as a measure of the talking efficiency of the circuit under test. At first this comparison was made by ear. Those who are familiar with the technique of telephony realize that this was a laborious and rather unprecise method of comparison.

Many readers also realize the difficulties which lay in the way of the development of more precise methods, either of computation or of measurement, because of the nature of telephone currents and the characteristics of telephone circuits. The currents which transmit conversations over telephone cir-

cuits consist of groups of complicated electrical oscillations, each group, in general, representing a syllable, the groups following each other in rapid succession along the circuit. This is illustrated by the oscillogram shown in Figure 1. On the average, the syllables are approximately 0.2 second in length. While at first glance, these oscillations seem to be quite transient in character, if certain parts are repeated on a more rapidly moving film, as in Figure 2, it is seen that they are periodic in character. Generally speaking this applies to the vowels, which are sustained long enough to have this periodic character, while the consonant sounds are short and transient.

The direct application of exact mathematical analysis to the propagation of these complicated groups of oscillations over long and complex telephone circuits, and to the acoustic-electric transformations in the telephone transmitter and receiver, is impracticable. As is the case in many types of practical problems, the physical processes involved are far too complicated to be handled in this way. However, the telephone transmission problem lends itself to indirect mathematical treatment of great practical value. The complicated oscillations can be considered as formed by the combination of a large number of simple single frequency currents. The mathematical treatment of the transmission over telephone circuits of these single frequency components had not been developed in the early days of telephony, but has now been developed to a high point.

The analysis by experimental methods of the telephone currents shows that, while theoretically their single frequency components cover a very wide range of frequencies, the most important part of this range is between 300 and 2,700 cycles. A study of the transmission of single frequency components throughout this range gives then a means of determining the quality of transmission of the telephone currents. Fortunately for many types of case the relative loudness of sounds reproduced from telephone currents can be determined by studying the efficiency of transmission of one single frequency com-

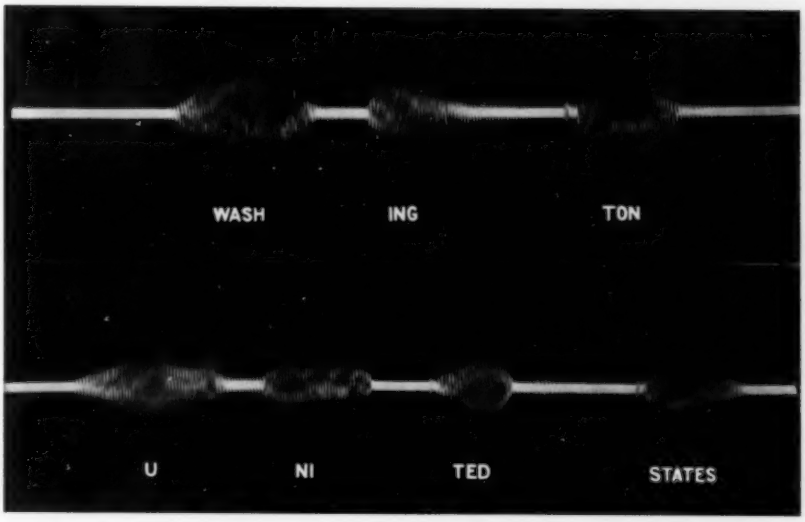


FIGURE 1. OSCILLOGRAM SHOWING THE TELEPHONE CURRENTS PRODUCED WHEN THE WORDS "WASHINGTON, UNITED STATES" ARE SPOKEN INTO THE TELEPHONE TRANSMITTER. These currents consist of groups of complicated oscillations, each group in general representing a syllable.

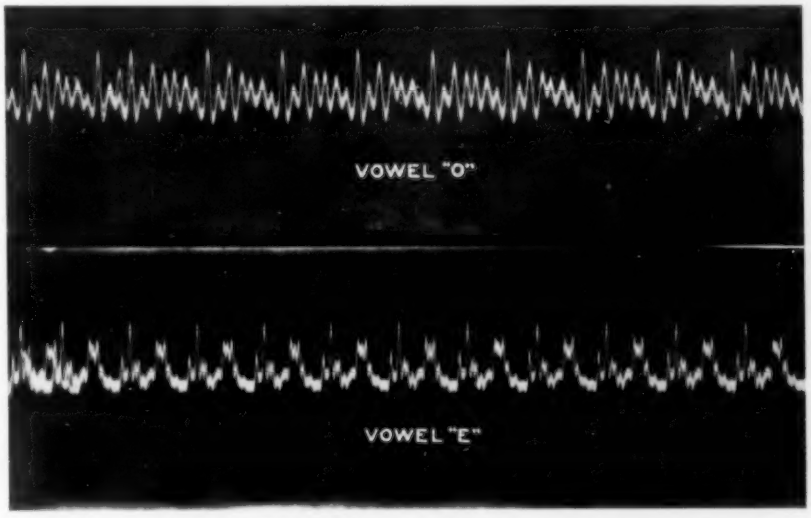


FIGURE 2. OSCILLOGRAM SHOWING IN DETAIL THE TELEPHONE CURRENTS PRODUCED WHEN THE VOWELS "O" AND "E" ARE SPOKEN INTO THE TELEPHONE TRANSMITTER. The speed of the film was about ten times that of figure 1. These currents are periodic in character.

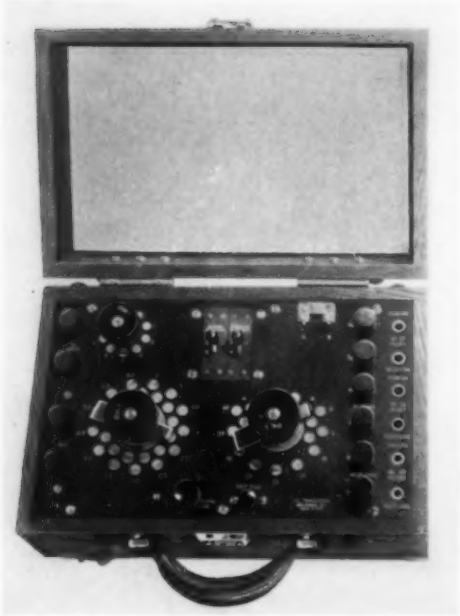


FIGURE 3. EARLY TYPE OF TRANSMISSION MEASURING SET USING 1000 CYCLE CURRENT WITH EAR BALANCE MEASUREMENTS.

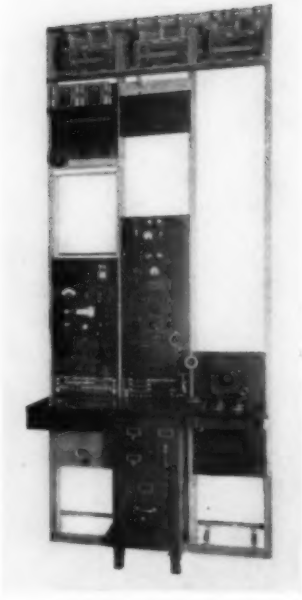


FIGURE 5. MODERN TRANSMISSION TESTBOARD FOR USE IN TOLL OFFICES, SHOWING THE TRANSMISSION MEASURING SET IN THE LOWER LEFT PANEL, THE ASSOCIATED OSCILLATOR AND AMPLIFIER IN THE CENTER PANEL AND AN IMPEDANCE BRIDGE IN THE LOWER RIGHT PANEL.

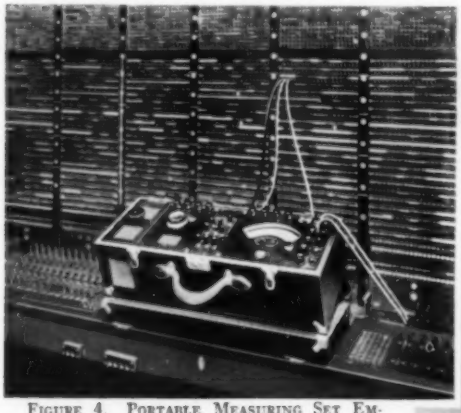


FIGURE 4. PORTABLE MEASURING SET EMPLOYING AN AMPLIFIER AND METER, SHOWING THE SET IN USE FOR TESTING SWITCHBOARD CIRCUITS.

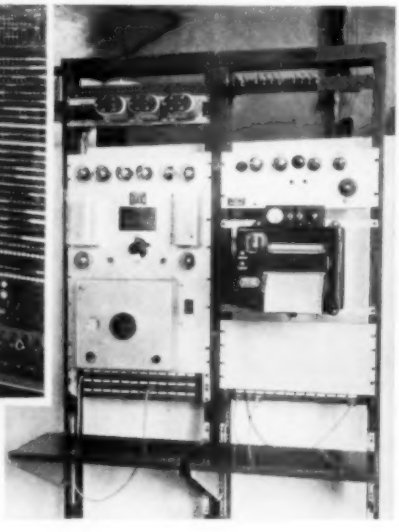


FIGURE 6. EXPERIMENTAL MODEL OF AUTOMATIC RECORDING TRANSMISSION MEASURING SET ARRANGED TO PRODUCE A GRAPHICAL RECORD OF TRANSMISSION EFFICIENCY AS A FUNCTION OF FREQUENCY OR OF TIME.

SEVERAL TYPES OF TRANSMISSION MEASURING SETS

ponent, thus greatly simplifying a very complex problem. The frequency used for this purpose is 1,000 cycles.

Although the theory of transmission of single frequency currents, as applying to telephone circuits, has now been highly developed, it would be quite out of the question to make a precise computation in each case of the efficiency for even one frequency, such as thousand cycles. For practical telephone work it has been necessary to develop methods of approximation and simplification and to prepare by these methods tables and curves from which an approximate answer can be quickly obtained in practical cases. The overall efficiency of the electrical part of a telephone circuit is often in the order of one per cent or a fraction of one per cent, that is, 1/100 or less of the transmitted power is delivered at the receiving end, and the approximate methods in current use enable this efficiency to be quickly estimated with a precision sufficient for usual engineering work.

Methods must be available not only for computing the talking efficiency of telephone circuits, but also for measuring it. Here again the electrical efficiency of transmission of a single frequency component can be used as a practical approximation to the talking efficiency as long as the loudness of received sounds is the criterion. However, conditions for this measurement are so different from those of ordinary alternating current measurements that the methods used for power circuits cannot be applied to telephone circuits. The telephone currents at the transmitting end of a circuit do not exceed one or two milliamperes in amplitude and at the receiving end are often only a few microamperes. Measurements on telephone circuits must, in general, be made with currents of magnitudes and frequencies comparable to those of currents transmitting conversations because the efficiencies vary with both the magnitude and the frequency of the currents. When measurements first became generally important, the problem was so to design telephone transmission measuring equipment that a measurement

which at that time was a delicate laboratory operation could be made on a large scale by plant men without special training as a part of their routine job.

This has been accomplished with a high degree of success. In the earliest transmission measuring sets, as indicated in Figure 3, the comparison was by ear, thousand cycle alternating current being transmitted alternately through the testing apparatus and over a circuit which looped back to the sending point, and the current received through the testing apparatus adjusted to be of equal loudness to that received over the circuit. With the development of amplifiers, however, it became practicable to show the received current on a meter. An early type of this kind of apparatus, portable in character, is shown in Figure 4. Figure 5 shows a modern transmission testboard for use in large toll offices. An interesting further development which has been made experimentally is an automatic recording measuring set (Figure 6) by means of which within a minute a record is made of the transmission efficiency of a circuit over the entire range of telephone frequencies.

So far the discussion has related principally to the electrical part of the circuit. However, the overall efficiency of a telephone circuit depends also on the efficiency of conversion from acoustic to electric oscillations in the transmitter and from electric to acoustic oscillations in the receiver. In the early standard of reference in which efficiencies were judged by comparing the loudness of transmission with that over a typical circuit, this factor was, of course, included although in a rather crude way. Standards of comparison for these acoustic-electric conversions have since been established both for the transmitter and for the receiver and these, combined with means for adjusting the circuit efficiency as desired between the standard transmitter and receiver, give a complete standard reference system. The system which was adopted as standard is an idealized system giving nearly perfect reproduction of sounds

between transmitting and receiving ends. The assembly of apparatus involved is indicated in Figure 7.

Other Factors Affecting Talking Efficiency

In the ways described above, a very complete technique has been developed for both computation and measurement of the electrical efficiency of telephone circuits and for expressing this efficiency in terms of transmission units in a standard reference circuit adjusted to the same overall efficiency. However, while this method of rating telephone circuits was being perfected, it even then was becoming little by little less adequate. The purpose of the telephone circuit is not fundamentally the transfer of electrical energy from one point to another, but it is the transfer of information. The power efficiency is of interest because it represents the loudness of reproduced sounds, and this in turn is one of the important factors determining the ease with which the transfer of information is made, that is, it affects the talking efficiency of the circuit. But from an early day, other factors appeared in the problem, and they rapidly became of increasing importance.

These factors include the other noises heard by the man listening to the telephone conversation—noises present in the room where he is listening and noises produced in the receiver by currents arising from induction from other electrical systems. If noise from any of these sources is great, the received conversation obviously must be louder than otherwise would be required. The loudness of room noises varies over a surprising range from place to place. This is indicated by Figure 8. The reader will note that the energy level of noise varies over a range of one million to one as between very noisy and very quiet locations.

A second factor is the variation in the efficiency of transmission of the different components of the telephone currents. Such variations have always been present in telephone circuits, but in the early days the circuits were sufficiently similar in

their characteristics to make this factor unimportant for their comparison. But transmission over longer and longer distances

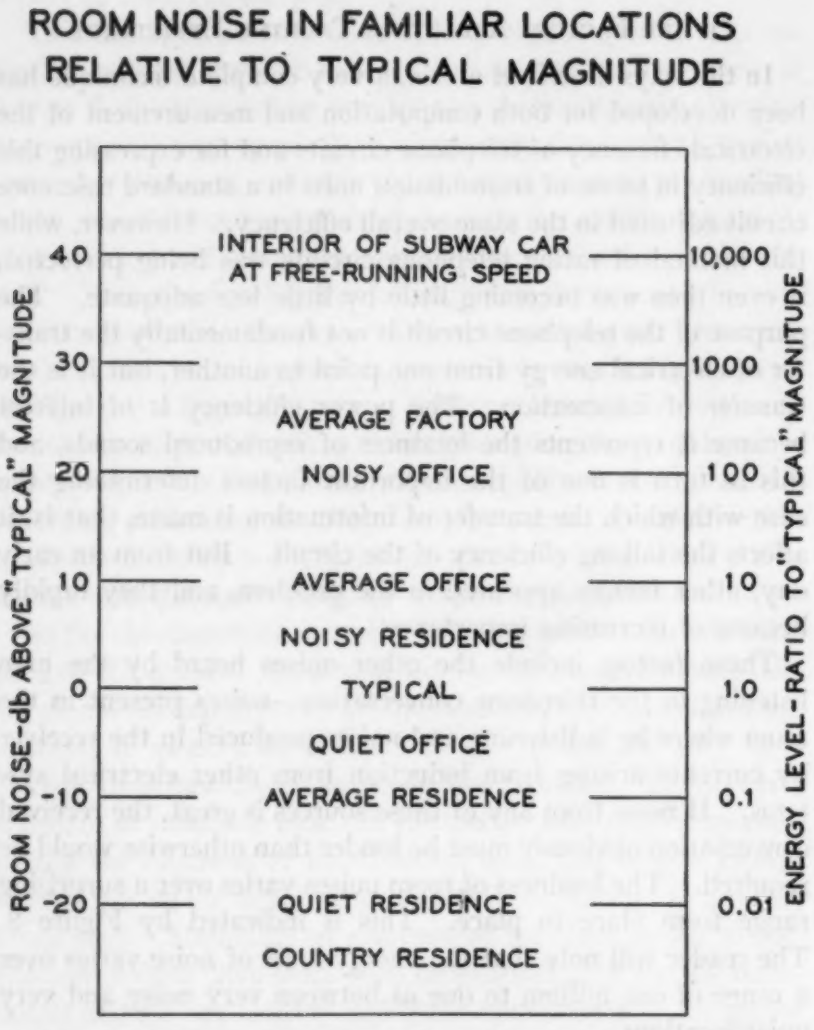


FIGURE 8. THE RANGE OF LOUDNESS OF ROOM NOISE IN FAMILIAR LOCATIONS.

was based on the use of new types of telephone circuit, particularly loaded circuits, markedly different in their characteristics from the non-loaded circuits which had preceded them. Fig-

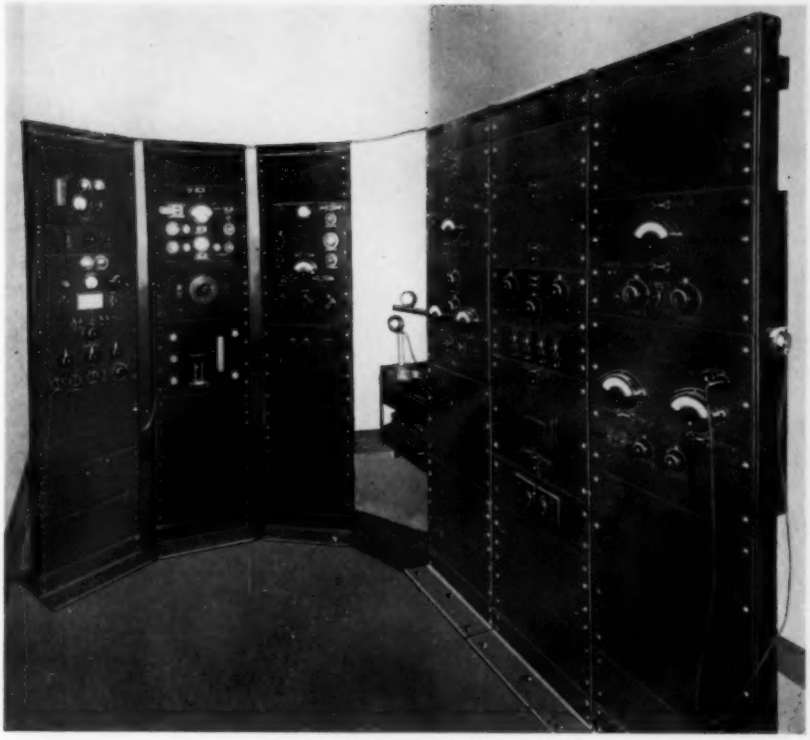


FIGURE 7. ASSEMBLY OF MASTER REFERENCE SYSTEM FOR TELEPHONE TRANSMISSION WITH ASSOCIATED CALIBRATION APPARATUS. The transmitter, line and receiver are shown at the right, and the calibration apparatus at the left.

FIGURE 10. DISTORTION OF THE SHAPE OF WATER WAVES RESULTING FROM THE VARIATION IN THE VELOCITY OF TRANSMISSION OF THE DIFFERENT FREQUENCY COMPONENTS.

FIGURE 11. OSCILLOGRAPH SHOWING THE DISTORTION OF ELECTRICAL WAVES IN TELEPHONE CIRCUITS RESULTING FROM DIFFERENCES IN THE VELOCITY OF PROPAGATION AT DIFFERENT FREQUENCIES. The upper curve shows a compound wave consisting of 800 cycles and 1,600 cycles at the transmitting end of a 600-mile medium heavy loaded repeatered cable circuit. The lower curve shows the received wave after amplification, the distortion resulting in the 800-cycle component being received first, followed by the 1,600-cycle component.

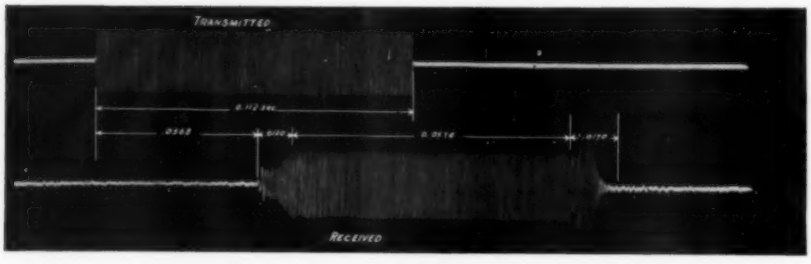


FIGURE 12. DISTORTION OF THE ELECTRICAL WAVES IN TELEPHONE CIRCUITS RESULTING FROM TRANSIENT EFFECTS. The oscillograph of the transmitted and received waves for a 1,600-cycle impulse sent over a 522-mile medium heavy loaded repeatered circuit shows the gradual building up and dying out of the received wave.

ure 9, for example, shows the electrical efficiency at various frequencies in the telephone range of three types of telephone circuit in cable: first, 8½ miles of non-loaded 19 gauge cable representing the early art; second, 100 miles of heavily loaded 19 gauge cable representing the long distance art of 20 years ago; and third, 1,000 miles of lightly loaded 19 gauge cable representing the art of today. The modern 1,000 mile circuit has a better characteristic than either of its shorter predecessors. Another cause of difference in frequency characteristics is the difference between the various types of telephone instruments in use. An instrument which has a wide variation in efficiency of acoustic-electric conversion over the range of

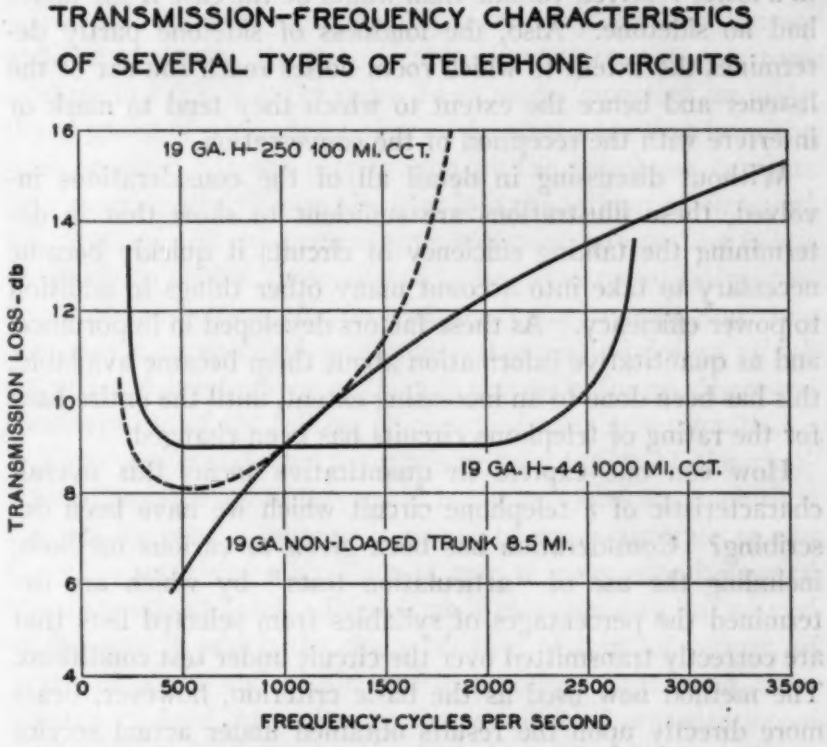


FIGURE 9. ELECTRICAL EFFICIENCY AT VARIOUS FREQUENCIES OF THREE TYPES OF TELEPHONE CIRCUITS. The modern 1,000-mile circuit has much better characteristics than either of the shorter earlier types shown.

telephone frequencies gives, for an equal loudness, materially less clear conversations than an instrument having a flatter characteristic.

Still another important factor is the effect of "sidetone"; that is, the reproduction in the telephone receiver of the voice of one speaking in the transmitter of the same set and of room noise picked up by this transmitter. The loudness of sidetone varies materially under different conditions, with a corresponding variation in the effect on telephone transmission. With a large amount of sidetone, a person tends to talk at a lower volume level because hearing his own words loudly repeated in his ear gives him a sensation of speaking loudly. This results in a lower received volume than would be the case if the talker had no sidetone. Also, the loudness of sidetone partly determines the extent to which room noises reach the ear of the listener and hence the extent to which they tend to mask or interfere with the reception of the conversation.

Without discussing in detail all of the considerations involved, these illustrations are sufficient to show that in determining the talking efficiency of circuits it quickly became necessary to take into account many other things in addition to power efficiency. As these factors developed in importance, and as quantitative information about them became available, this has been done to an increasing extent, until the entire base for the rating of telephone circuits has been changed.

How can one express in quantitative terms this overall characteristic of a telephone circuit which we have been describing? Consideration has been given to various methods, including the use of "articulation tests" by which are determined the percentages of syllables from selected lists that are correctly transmitted over the circuit under test conditions. The method now used as the basic criterion, however, bears more directly upon the results obtained under actual service conditions. It makes use of the frequency with which repetitions occur in actual conversations. This has been determined

for commercial conditions by observing conversations between telephone employees using tie trunks between various parts of the telephone organization. The characteristics of these tie trunks have been modified from time to time to represent various conditions of noise, distortion, volume efficiency and sidetone, and the effect on the number of repetitions noted. Two circuits are said to have the same talking efficiency when their repetition rates are the same for the same service. Taking one form of circuit as a basis of reference, the talking efficiency is expressed in terms of the volume efficiency of this circuit when adjusted to give the same repetition rate.

Effect of Time of Propagation

The development of telephony over very great distances, and, subsequently, the use of cable circuits for distances running up to 2,000 miles or more, have made important an additional group of phenomena of great interest, resulting from the time required for the propagation of the telephone currents over the circuits. These all enter into the talking efficiency of the circuits. At the present time sufficient information is not available to enable these effects to be rated quantitatively in terms of the volume efficiency of a reference circuit, but they are limited to specified maximum values in the design of the circuits. A brief review of them is necessary for an all-around consideration of the talking efficiency of telephone circuits.

There appears to be a surprising adaptation of the characteristics of things in this world to the purposes to which they are put by man. Perhaps it would be more accurate to say there is a surprising adaptation of man to make effective use of the materials at hand. Be that as it may, one can but marvel at the way in which the characteristics of iron, of copper, of wood, of water and of air, not to mention a thousand other substances, lend themselves to the complicated organization of machinery and of structures which form the skeleton of our industrial society, and even more important, how certain of

these materials and the conditions of temperature and climate which surround the earth, lend themselves to the maintenance of that most complicated organization, life. Similarly, there appear to have been provided just the right conditions for universal electrical communication in this world. If communication were dependent upon acoustic methods, telephone conversations over long distances would naturally be out of the question. The time of propagation, for example, between New York and Chicago would be more than one hour, and an equal time would be required for the transmission of each response. However, the maximum velocity of propagation of electromagnetic waves, 186,000 miles a second, is such as to make possible transmission between any two points on the earth's surface in about 1/15 of a second, a time delay small enough to be satisfactory for conversations.

This maximum velocity of propagation of electromagnetic waves is by no means the velocity of propagation over all types of telephone circuit. Early types of loaded cable circuit had a velocity of about 8,000 miles a second. While suitable for moderate distances, this would cause trouble for such distances as separate remote parts of our own country. However, the development of long distance transmission through cables required, for other reasons, the development of circuits having a higher velocity and the circuits used for long distance cable transmission today have a velocity of about 20,000 miles a second. This is quite adequate for the distances, running up to 2,500 miles, for which cable is used in telephony at the present time. Nevertheless, the time intervals required for transmission are quite appreciable, the interval for 2,500 miles being approximately one-eighth of a second in each direction, and for the much longer cable circuits which are expected with future extensions of the cable network, higher velocities of propagation will be used.

Associated with these and the smaller intervals corresponding to smaller distances are some interesting phenomena which

affect the clearness of transmission. One of these is described as an "echo." It results from the fact that the telephone currents, transmitted at high efficiency over the telephone circuit, are partially reflected at the end of the circuit and return to the telephone of the talker. If the time required is more than a few hundredths of a second, even a small percentage of returned current is noticeable as "echo" and produces a certain amount of interference with the conversation. The greater the loudness of the echo or the greater the time delay, the greater is this interference.

Another type of effect results from the fact that the different frequency components of the telephone currents tend not to be transmitted at exactly the same speed. The result is that certain components of the voice currents arrive a little before others, with a resulting distortion of the quality of the speech. This type of effect is graphically illustrated by waves in water which have a large amount of distortion of this kind. Figure 10 shows the wake of a boat. If water waves were without distortion the wake would consist of long uninterrupted crests and troughs, the angle with reference to the direction in which the boat is traveling showing the relative speed of the boat and of the wave. Actually in deep water the low frequency components of waves travel more rapidly than the high frequency components. The resulting distortion of wave shape leads to the form of wave shown in the photograph in which the main body of the wake appears to be broken up into a number of short sections and each short section appears to travel more rapidly than the group of waves as a whole. It is clear that if one should endeavor to transmit speech by creating water waves having the form of articulate sound, it would not be intelligible at the receiving end because of the great distortion of wave shape during transmission, the low frequency components arriving earlier than the higher frequency components.

In telephone circuits fortunately the difference in velocity of transmission, or the delay distortion as it is commonly called, is

relatively small. It may, however, under some conditions have an important effect on the talking efficiency. Figure 11 illustrates this fact. It shows a compound wave consisting of 800 cycles and 1,600 cycles transmitted over 600 miles of medium heavy loaded cable circuit. It will be noted that the 1,600-cycle components were received at a time materially later than the 800-cycle components. Figure 12 shows the same type of effect with an impulse of single frequency current. Here the effect can be described as a gradual building up and a gradual dying out at the ends of the impulse as it is received at the end of the circuit, that is, the transient effects which accompany the transmission of the impulse. These effects depend on both the type and the length of circuit, and in practise they are limited to amounts considerably less than shown in the figures by limiting the length for which each type of circuit is used.

Conclusion

This review of the factors which determine the talking efficiency of telephone circuits, because it is brief, is necessarily superficial. It is intended, however, to indicate in a general way what the problem is and how it has been tackled. In many respects these problems dealing with complicated electrical phenomena are very rewarding things to work with. They are sufficiently complex and difficult to stimulate interest and effort, yet they are not wholly recalcitrant for they yield, one after the other, to the assault of the scientist and engineer. And while from the standpoint of electrical phenomena, results are obtained which are quite tangible and definite, and can easily be verified by experience, the author hopes it is quite clear that the problem is much more than an electrical problem. The measurement of the degree to which the telephone circuit satisfactorily fulfills its function of enabling people to talk easily with one another at a distance involves not only the electrical and acoustic characteristics of the circuits and tele-

phone instruments, but also the study of service from the standpoint of the satisfaction derived by those who use it. It is an illustration of a recurring problem whose solution has been one of the great things that has stimulated the development of modern commerce and industry, that is, the measurement of results achieved not on the basis of some technical effect which happens to be easy to measure, but from the broader point of view of determining as nearly as possible the degree of satisfaction given to the customer.

H. S. OSBORNE

Protection Against Lightning

Editor's Note:

The April issue of the BELL TELEPHONE QUARTERLY *contained an article on Lightning, which referred in general to various investigations in that field together with some of the resulting facts and theories. The following article deals more particularly with methods of protection against lightning.*

PROTECTION OF STRUCTURES

FRANKLIN'S proposal to protect buildings by lightning rods led to many interesting incidents. Since lightning was looked upon by many as an instrument of punishment for human wickedness, the use of lightning rods was vigorously opposed by the superstitious element in the church. In several instances mobs of fanatics tore down the "heretical rods," as they called them. In one such case in northern France which resulted in litigation, Robespierre, at that time an unknown young man, was the lawyer who pleaded in court in behalf of the lightning conductors and won the suit.

After Franklin set his hand to the Declaration of Independence, the opposition to lightning rods in England assumed somewhat of a political aspect. For years a controversy raged as to whether the air terminals for the rods should be topped with balls or sharp points, the use of points, as recommended by Franklin, finally prevailing.

The first installation of lightning rods on a public building in Europe was that on the Church of St. Jacob in Hamburg in 1769. The use of rods spread rapidly in northern Germany. Gradually in the southern countries of Europe also, lightning conductors gained in favor, largely through the activities of a few enthusiasts. One night, under cover of darkness, a zeal-

ous follower of Franklin installed rods on the Cathedral at Siena. This created great indignation but the enemies of the rods were appeased when they found, after a heavy storm during which the Cathedral was terrifically bombarded by lightning, that the structure remained uninjured. Shortly thereafter rods were erected on the observatory of the University of Padua. Here again an angry crowd became pacified when, after seeing lightning strike the observatory, they found that it caused no damage. On May 9, 1778, the Senate of Venice issued a decree ordering lightning rod protection for public buildings, this being the first official recognition of lightning rods by any government. Important buildings such as the Louvre in Paris, St. Peter's and the Vatican in Rome, and the Houses of Parliament and St. Paul's Cathedral in London, were later equipped with rods.

A remarkable lightning rod installation was designed for the City Hall in Brussels. The equipment was very elaborate and included some 60 "aigrettes" or elevation rods having a total of more than 500 points. The three ground electrodes had a total contact area of more than 2½ million square feet. In 1889 Oliver Lodge said:

> "Of all the buildings in the world not wholly made of metal, the Hotel de Ville at Brussels was and is the most perfectly and elaborately protected. No electrician exists who would not a year ago have asserted, had he gone over it, that it was absurdly and exaggeratedly safe from damage by lightning. Last July it was struck and set on fire."

Thus we see that no system of lightning rods affords absolute protection, although it should be mentioned perhaps that in this case the fire was due to the ignition, by an induced spark, of gas from a leaky main.

In England regulations for the installation of lightning protection were issued by the Lightning Rod Conference in 1881. In 1901, the Lightning Research Committee was organized jointly by the Royal Institute of British Architects and the

Surveyors' Institute. An important report by that committee was presented in April, 1905.

In Germany rules for the protection of buildings were issued by the Electrotechnische Verein in July, 1901.

Specifications for lightning rod protection were issued by the Italian War Ministry in 1919 and by the Swiss Association of Electrical Engineers in 1923.

In Ontario, Canada, regulations covering lightning rod installations were put into effect by the Provincial Fire Marshal in 1922.

In the United States the installation of lightning rods has been carried on largely by manufacturers and contractors without public regulation. For many years lightning rods were sold to farmers and others by traveling agents, many of whom supplied inferior material at inflated prices. Often the lightning rods were not properly installed and no attention paid to their maintenance. As a result lightning rods fell into disrepute and the idea widely prevailed that they were nothing but a humbug. Gradually, however, this misapprehension was dissipated, as more competent persons gave attention to the subject and the business of manufacturing and installing the equipment passed into more reliable hands.

A circular on protection against lightning was issued by the U. S. Bureau of Standards in 1915 and the U. S. Weather Bureau also has issued several bulletins on the subject. In 1921 a joint committee was formed by the national organizations interested, to codify approved practice in lightning protection. The outcome of this work, a "Code for Protection Against Lightning," was approved by the American Standards Association, April 4, 1929. The code has been printed as "Miscellaneous Publication of the Bureau of Standards, No. 92." Practically identical specifications have also been issued by the National Fire Protection Association.

Protection by Lightning Rods

When lightning strikes a building, a large amount of energy is suddenly impressed upon the material through which the current passes. Much of this energy is converted into heat and the material in the lightning path, if combustible, is liable to be set afire. If the material is non-combustible, such as brick or stone, moisture or other matter contained in it may be volatilized by the heat and the resulting gas, expanding with explosive violence, may split or shatter the material.

The purpose of lightning rods is to provide a path by which a discharge from a thunder cloud above the building may reach earth without passing through the material of the building itself. Visualizing the discharge as progressing downward from cloud to earth, the first essential of a lightning rod installation is to provide at the top of the building means for intercepting the lightning current as it comes from the cloud. For this purpose vertical conductors called "elevation rods" are placed at intervals along the ridgepole or other topmost part of the building. These elevation rods are usually about 2 feet in height, but in some cases may be 4 or 5 feet high in order to extend above chimneys or other vertical projections. From considerations of mechanical strength the elevation rods have to be of substantial construction and suitably braced. It is customary to terminate the tips of the elevation rods in "points" since the discharge of a charged body tends to concentrate at any sharp points which the body may have. It has even been supposed by some that the points of a lightning rod installation are able to draw the electricity out of the cloud silently and continuously and thus make impossible the occurrence of violent and dangerous strokes. This supposition, however, is erroneous, as can readily be seen by comparing the physical dimensions of lightning strokes with the maximum distance through which the influence of a "point" could possibly extend, and it is now recognized that the use of points is of minor importance.

After capture of the discharge from the cloud by an elevation rod, the next essential is to keep the lightning current on the lightning rod system until it is conveyed safely to earth. To accomplish this the bases of the elevation rods are connected to a system of metallic conductors coursed along the ridgepole, or other pinnacle of the roof, and down the corners or sides of the building to the ground in such a way as to approximate roughly an enclosing network. For a small or medium building, down-conductors at two or three corners respectively are usually sufficient, but on a large building four or more down-conductors are desirable.

The lightning conductors need not be insulated from the building. Any metal such as gutters, leaders, flashing, etc., is bonded to the lightning rod system, as are also pipes and other large objects of metal inside the building, unless the lightning conductors are kept 6 feet or more away from such interior metal.

Each down-conductor is extended to earth and connected to an underground electrode, for which purpose an extensive metallic water piping system is most effective. Where a water pipe is not available, the best earth connection can usually be secured by means of driven pipes or rods, the individual rods being 6 feet or more apart and securely bonded together.

The lightning conductors may be of copper or of galvanized or copper covered steel and may be in the form of stranded cable, solid rod, or tubular or other cross-section, such as tape or ribbon. The kind of metal employed or its size or form is not of great importance so far as determining the discharge path is concerned, but is governed by considerations of mechanical strength, durability, facility in handling and in making connections, etc.

Protection by Means Other Than Rods

Buildings of steel frame construction and buildings covered with metal sheathing or having metal roofs do not require

lightning rods, but the metal should be thoroughly grounded. A building situated amidst tall trees derives substantial protection from the trees. A metal tower, such as a windmill, if within 50 feet or so of a building, offers material protection, particularly if it is taller than the building. An array of tall metal masts or poles, thoroughly grounded and interconnected, encircling a building would probably afford better protection than lightning rods. A deposit of radium or other radioactive substance produces, by ionization of the air, a conductive path for lightning, and such a deposit might constitute reasonably effective protection for a near-by house.

Where it is deemed advisable to equip a structure with lightning rods, the specifications contained in the national Code for Protection against Lightning represent accepted modern practice. It is, of course, important that the installation be supervised by an engineer or other competent person experienced in this field.

Special Types of Structures

Towers, monuments, stacks and other unusually tall structures, are more exposed to damage by lightning than ordinary buildings and the national Code for Protection against Lightning includes special precautions for such structures. The Washington Monument, for example, has been struck by lightning repeatedly and, before the lightning rods on it were properly interconnected with the structural metal, was considerably damaged.

Structures containing highly inflammable material such as oil tanks, gas holders, etc., are particularly hard to protect against lightning and the national Code contains a special section devoted to structures of this kind. In an ordinary lightning rod installation there is a possibility that small sparks may be induced between metal objects not thoroughly bonded together. The occurrence of such sparks in ordinary buildings may not be important, but in structures containing inflammable

liquids or gases, is liable to cause fires or explosions. Even with the extreme precautions observed in this special class of structures, the protection obtainable can not be considered absolute.

Effectiveness of Rods

There is no adequate information available to show just how effective lightning rods are in protecting an ordinary building. Merely as an expression of the writer's opinion, the chance of fire or mechanical damage by lightning to a properly rodded building is probably of the order of 10 per cent of what it would be with no protection.

Economics of Lightning Protection

In most localities lightning constitutes a substantial fire hazard to rural structures, particularly barns and silos which, being large, and possibly also harboring sources of ionization, are targets for strokes of lightning. The fire loss from lightning in the United States averages about $12,000,000 per year, practically all in rural areas.

From a strictly economic standpoint, the property loss due to lightning is not large enough to justify rodding all farm buildings, even if it be assumed that such rods afford 100 per cent protection, as the annual charges for the rods would amount to many times the total annual property loss from lightning. Obviously, therefore, economic justification for lightning rods can be found only where some unusual condition exists, which warrants extraordinary precautions against damage, such as unusually severe exposure, or unusual importance or value of building or contents. Of course the direct property loss of a burned building may not be the whole story. Indirect losses from inconvenience, interruption of use, and disturbance to operations on the premises, may exceed the appraisable property loss.

Effect on Personal Safety

We have seen that the air behaves in part like an insulator and in part like a conductor, the conductive regions being those in which, for the moment, free ions are abundant. When the space immediately about us becomes highly ionized, we find ourselves virtually inside a conductor and if this conductor happens to become a discharge path for lightning, our conductive bodies may be commandeered by nature to reinforce the conductive air with unpleasant or disastrous consequences.

While some people are beset with fear during thunder showers, actually the danger is small, particularly to persons inside buildings. The number of persons killed by lightning in the United States is, on the average, about 500 per year, which is less than one-twentieth of 1 per cent of deaths from all causes. In addition, there are in an average year some 1300 cases of shock by lightning which do not result fatally and most of which leave no serious effects. Statistics do not show how many of the injuries due to lightning occur to persons indoors, but it must be a small percentage of the total cases. Inside buildings of steel frame construction or having wall and roof coverings of grounded metal, there is practically no danger. To be inside a building of any kind is much safer than to be out in the open during a heavy thunder shower.

The question is often asked, do lightning rods insure safety to persons inside the rodded buildings? Undoubtedly the rods promote safety, but it may be worth while to examine the matter more closely. Proper installation requires that lightning rods be interconnected with conduits, pipes, and other extensive bodies of metal in the building. When the rods are struck they become momentarily charged to a high potential and this high potential is communicated to the interconnected metal. If a person should be touching a water faucet, for example, at the instant of a lightning stroke, he would be more liable to receive a shock than if the building were not rodded. For a condition of this kind the lightning rods enhance, rather

than reduce, the personal hazard. But if one keeps well away from the rods and all other large metal objects, the lightning conductors help to prevent the discharge from reaching his body and hence reduce the chance of shock.

When out of doors and away from buildings during a thunder shower it is natural to seek shelter under a tree, but an isolated tree in an open space is an inviting path for lightning and if the tree should be struck, a person under it would be liable to be injured. On the other hand a forest or grove affords a degree of protection because a lightning discharge in the vicinity would probably not be intercepted by the particular tree under which the person is sheltered.

Hollows, depressions, and low places generally are less subject to lightning than higher elevations, other things being equal. However, such differences in exposure may be entirely overshadowed by other factors. Thunder storms travel in courses determined largely by the local topography, direction of winds, proximity to water bodies, etc.; hence the influence of position on the liability to a lightning stroke can best be determined by local experience and observation.

Protection of Electric Power and Communication Lines and Apparatus

Most long distance communication circuits, practically all power transmission circuits, and most of the longer power distribution circuits, are of open wire construction and so require protection against lightning to a greater or less extent according to their importance and severity of exposure. A substantial amount of protection can be obtained by means of one or more shielding conductors carried along the line above the circuit conductors and grounded at frequent intervals. Such shielding is in use on many high voltage transmission lines in severe lightning areas. Also there is a growing tendency to attempt control over the number and location of failures by co-ordination of insulation, "co-ordinating gaps," and other

design features of lines and equipment. Relatively simple devices of tubular form, such as "expulsion gaps," "flashover protectors," etc., are being proposed for use in conjunction with external series gaps for protecting line insulators. The purpose is to afford a by-pass for lightning discharges, the devices being constructed with the idea of quickly extinguishing the follow-up current and so reducing insulation failures and circuit outages. As a further protection, particularly to apparatus, "lightning arresters" are employed on most exposed circuits. The arresters provide a path to earth for the lightning current, thus diverting it from the equipment to be protected. Such a device may be likened to a safety valve, its function being to relieve the abnormal electric pressure due to surges suddenly imposed on the circuit, before the abnormal stress breaks down the insulation which is being protected.

Protection of Communication Lines

From the earliest days of long distance electrical communication, it has been found necessary to use lightning arresters where aerial conductors of considerable length, and not in cable, are employed. The arresters are generally located at the junction of the exposed circuits and the plant to be protected. Conductors in metal sheathed cables, not connected to open wires or connected only to short lengths of open wire, are so well shielded that the effects of lightning on them and on their associated apparatus are usually negligible.

The protection used on communication circuits generally includes fuses although the purpose of the fuses is not to protect against lightning. Their use is due to the fact that in most cases the lines which are exposed to lightning are also exposed to the liability of accidental contact with electric power wires. Where exposed to such wires which carry more than about 250 volts, a fuse is needed in addition to a spark gap, the latter to provide a path to ground for lightning or

other abnormal current, the former to interrupt the current, if it is large enough to destroy the device or to start a fire.

Lightning arresters for communication circuits are designed on the principle of providing a discharge path for currents due to abnormal voltages, this path being in parallel with the portion of plant to be protected. The arresters are so designed and constructed that under normal conditions they do not divert any of the operating currents from their normal paths.

The arrester part of the protector commonly used on communication circuits is a simple spark gap, comprising two electrodes, separated from each other by an air gap of such size that it will break down and pass current from one to the other when the voltage between them exceeds a given value. In the arresters ordinarily used this air gap is of the order of .003 inch, and breaks down at about 300 volts.

In another class of lightning arresters used to a limited extent on communication circuits, the discharge takes place across a gap enclosed within a partial vacuum. Another type of arrester which is being developed makes use of a material having a critical voltage-resistance characteristic, that is, the material has a high resistance at the normal operating voltage of the circuit but a much lower resistance at higher voltages.

A great deal of work has been done in developing different materials for arrester electrodes and in experimenting with different shapes, dimensions, and methods of construction, in order to determine how the best results can be obtained. The present form of station protector is illustrated in Figure 1 and further details of construction are shown in Figure 2.

When installing the arresters, one of the two electrodes is connected to a conductor of the circuit to be protected, and the other electrode is connected to a ground, consisting of a water pipe if one is available, otherwise usually a rod driven into the earth. This type of arrester has functioned with a high degree of effectiveness, under its usual service conditions. The chief problem has been to obtain a device which, while

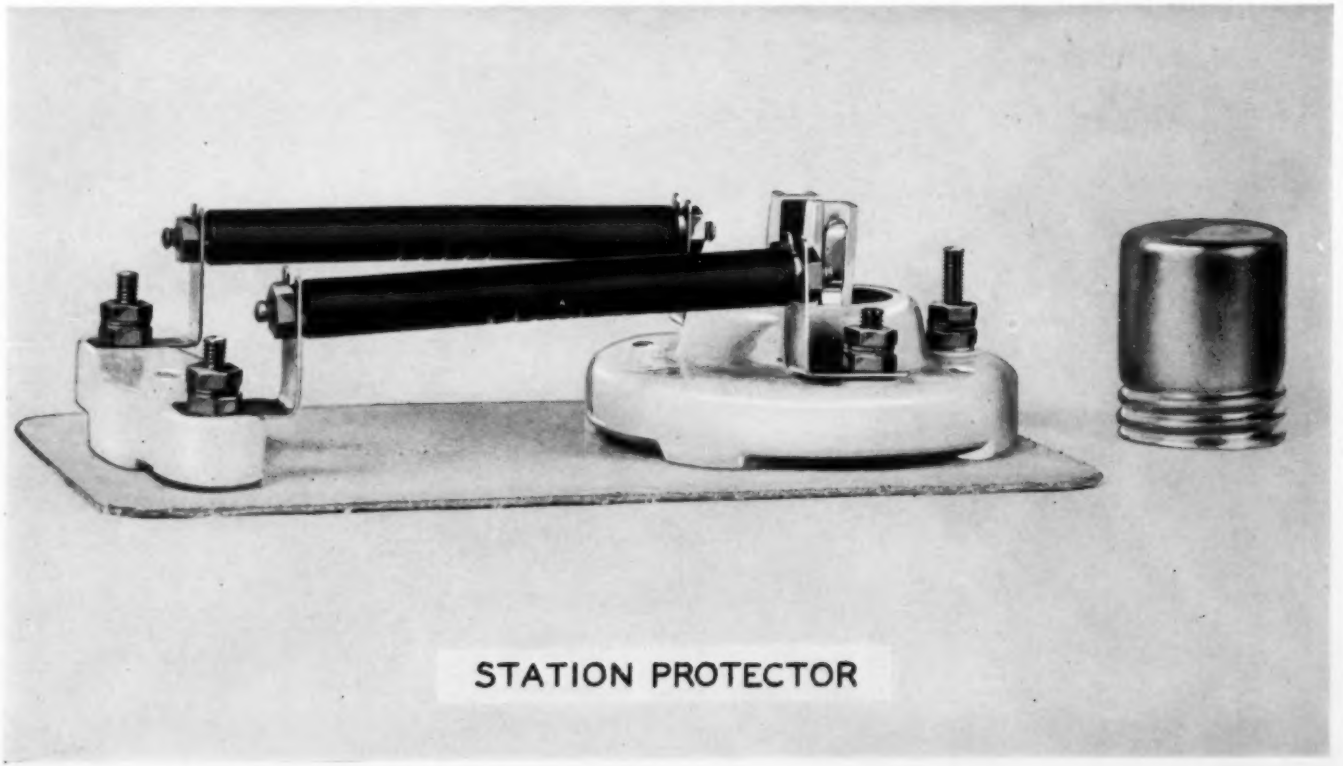


FIGURE 1.

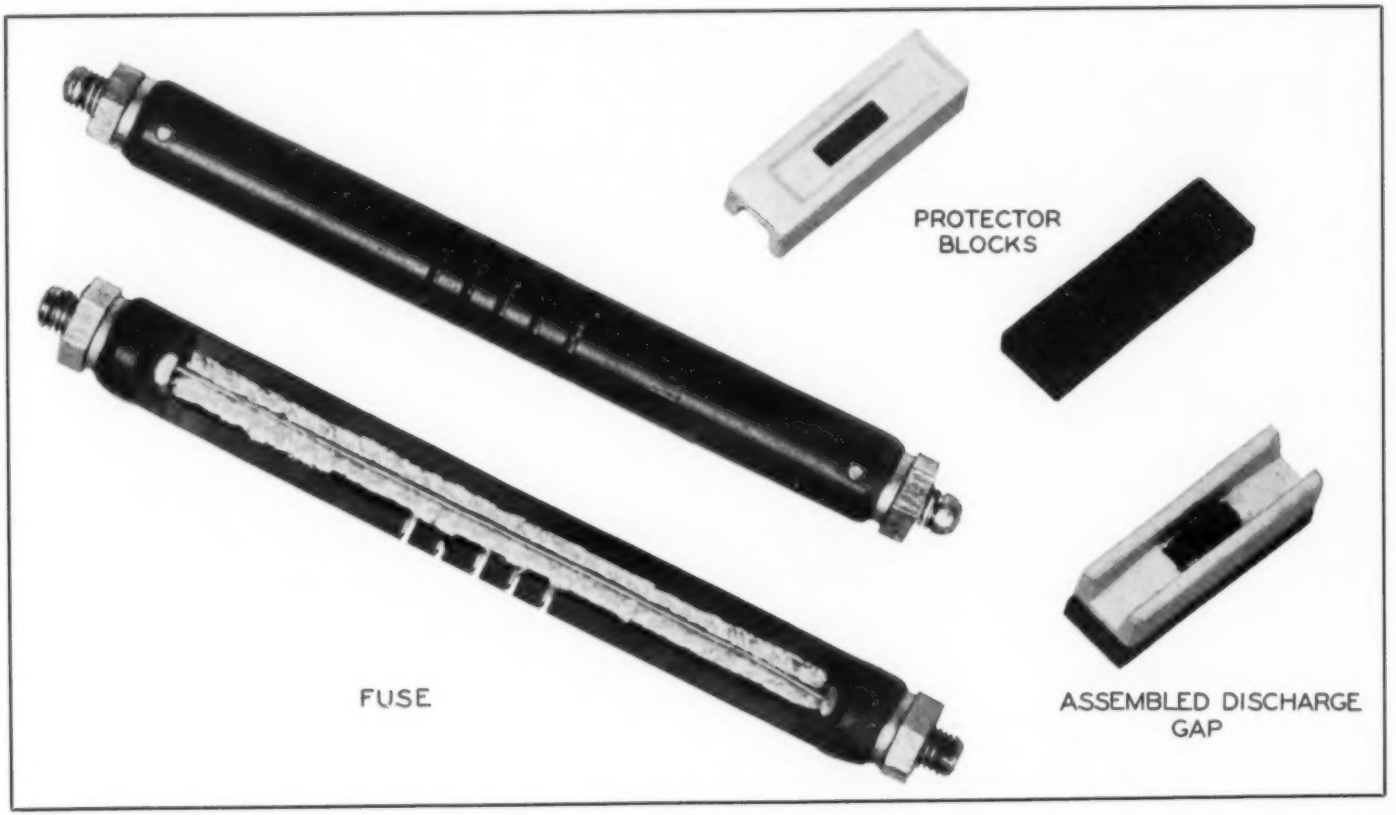


FIGURE 2.

adequate for protecting the cables and apparatus, would not suffer damage itself, thus disabling the circuit and causing interruption of service. It has been found that this trouble is reduced to a minimum by using electrodes of certain special types of hard carbon. However, the grounding of arresters is still a material source of trouble and the problem of improving the device is still an active one.

In areas where lightning is very severe it has been proposed to use two spark gaps in parallel, the second or auxiliary spark gap being of larger and more rugged construction than the regular one. The auxiliary gap is placed one or more poles away from the station protector, and is intended to take part of the discharge which otherwise would have to be handled by the regular arrester. This arrangement tends to lessen the chance of the discharge leaving the protector grounded and so causing interruption to service.

Arresters used at the junction of open wire and cable are similar to those used at subscribers' stations except that the spacing between the electrodes is somewhat greater. Formerly it was the practice to ground the cable arrester to a rod driven in the earth at the base of the pole, on the assumption that the most direct path to earth would afford the best protection. However, it has been found that the potential of the cable conductors due to lightning follows closely the potential of the cable sheath and that the cable can be protected more effectively by connecting the ground side of the arrester to the lead sheath of the cable rather than directly to earth. In this way the potentials of the cable conductors, the cable sheath, and the exposed open wires, are substantially equalized.

Most of the potentials imposed on communications wires by lightning are due to induction from strokes in the vicinity of the exposed lines. Direct strokes of lightning on telephone plant are of relatively infrequent occurrence.

The poles on which telephone wires are supported are sometimes shattered by lightning. In the early days of the tele-

phone it was the practice to carry a grounded conductor as a lightning guard wire along the top of the pole line, this conductor being tapped to earth every fifth or tenth pole. Later it became the practice to equip every tenth pole only with a wire down the pole to ground, like a lightning rod, the guard wire being omitted. Still later it came to be believed that even the vertical wires were not justified and their use was abandoned.

Recent experiments have indicated that the shattering of poles by lightning can be largely prevented by a wire extending from the top of the pole down to a point just below the lowest attachment on the pole, and terminating there instead of being carried clear down to earth. This arrangement avoids some, but not all, of the objections to the earlier types of pole protection and further study is being given to it.

For several years field tests have been conducted during the lightning season for the purpose of acquiring additional data on lightning behavior and characteristics incident to the problem of protecting telephone and telegraph systems.

Protection of Electric Power Lines and Apparatus

In the application of lightning arresters to electric power lines, the purpose is to protect, not only against lightning surges but also against sudden severe impulses due to other causes, such as switching, etc. A difficult feature of the problem is to obtain a device which will conduct the surge to earth before the potential rises to a dangerous value and at the same time will not permit the power current to follow up the arc; for power current follow-up would not only ground the circuit and interrupt service but would probably also destroy the arrester. For such service a simple spark gap is not adequate, except possibly for very low voltage circuits. In general, all arresters used on power circuits are provided with some means for interrupting the arc, as soon as the surge has disappeared.

All through the development of the electric power and light-

ing industry much attention has been given to the development of these protective devices. Many different forms of lightning arresters have been developed, most of which, after a period of more or less successful use, have been supplanted by new types of better design or greater effectiveness. Some of the more important of these arresters will now be mentioned.

The "Magnetic Blowout" Arrester

The "magnetic blowout" arrester dates from as early as 1881 and is still in use on railway and other direct-current circuits. In this arrester the spark gap electrodes are the poles of an electromagnet, the field of which, built up by the discharge current, extinguishes the arc.

The "Horn Gap" Arrester

In the early days of alternating-current power circuits, protection was attempted by the "horn gap" arrester. This consists essentially of a simple spark gap surmounted by a pair of V-shaped prongs, up which the arc is borne by the heated air and by magnetic influence until the arc, by increased length, becomes extinguished. As such an arrester is not adapted to carry heavy currents, series resistance was used to limit the current. This device has not for many years been generally used as an arrester by itself, but it has served a purpose as an element in protection arrangements in conjunction with later type arresters.

The "Multi-Gap" Arrester

Some thirty years ago, as power circuits of larger capacity came into use, an important advance in lightning protection was effected by the development of the "multi-gap" arrester. This consisted of a number of gaps in series between cylinders of "non-arcing metal," an alloy of low and high boiling point metals, the former to permit an arc to form at low temperature, the latter to hold the cylinders in shape. Due to capacity

effects, the surge voltage would not distribute evenly among the gaps, but the voltage across the end gap would be greatest. Consequently this would break down first, after which the greatest voltage would be impressed across the next gap, which would then break down, and so on. The operating circuit voltage, however, being of low frequency would distribute equally among the gaps, and under this condition none would break down. Furthermore, the power arc, which followed a surge discharge, would not re-form after extinction at the end of the half cycle. To care for surges of different wave fronts, etc., resistances were sometimes used in series or shunt with some or all of the gaps so as to form several discharge paths of different electrical characteristics. The arresters were often connected to the line through simple spark gaps shunted by fuses.

The multi-gap arrester was fairly satisfactory on low voltage circuits such as 2300-volt distribution circuits, but on higher voltage circuits, such as are used for transmission, the spark gap type of arrester was found incapable of extinguishing the arc quickly enough always to prevent the arresters from being destroyed and the circuits from being put out of service. About this time also various devices, many of which were essentially variants of simple air gaps, such as arcing rings for transmission line insulators, came into use. As the nomenclature was getting to be confused it was decided that the term "lightning arrester," as applied to protective apparatus for power systems, should henceforth be used only to indicate devices which, after being operated, would automatically restore to normal condition.

The "Aluminum Cell" Arrester

The electrolytic or "aluminum cell" arrester was the first important example of the so-called "valve" type, i.e., an arrester having an element which passes current freely at impressed voltages in excess of a certain value, and which ceases

almost completely to pass current at impressed voltages below a certain value. A horn gap or other spark gap is connected in series with this arrester.

The arrester comprises a series of cells having aluminum electrodes and an electrolyte in which aluminum is not soluble. In such an electrolyte a film of aluminum oxide forms on the electrode surfaces. This film breaks down at about 350 volts, but at any lower voltage is non-conducting. The current resulting from breakdown, however, restores the coating to its non-conductive state. By placing a sufficient number of such cells in series, any predetermined breakdown voltage can be obtained. This breakdown and the resulting restoration to the non-conductive condition, make the aluminum cell arrester act, towards an overvoltage, like a counter-electromotive force of magnitude equal to the normal circuit voltage. The discharge through the arrester is therefore limited to the short-circuit current of the over-voltage, the energy of which is small compared to the short-circuit capacity of the power circuit.

This arrester proved to be quite effective as a protector and came into extensive use, but its operating and maintenance cost was high, since, in order to maintain the film of aluminum oxide, it had to be charged daily by short-circuiting the series gaps for a few seconds. Also at very low temperatures the electrolyte would freeze and the protective properties become lost.

There are still quite a number of arresters of this type in service, but in recent years they have not usually been employed in new installations of alternating-current systems.

The "Oxide Film" Arrester

The next important improvement in the lightning protector field was the "oxide film" arrester, which also functions on the "valve" principle in a manner closely resembling the aluminum cell arrester, but has the advantage that it contains no electrolyte and does not require charging. The oxide film arrester comprises a series of cells, each consisting of two

circular metal plate electrodes, mounted on, and held apart by, a porcelain ring. The space inside the ring between the electrodes is filled with lead peroxide which is a good conductor, but when current passes through it, a film of the material in the current path is reduced to a lower oxide of lead which is an insulator. This insulating film grows in thickness until it cuts off further flow of current. The film can withstand a voltage up to about 300 volts per cell. At a higher voltage the film is punctured and the over-voltage is discharged, but in so doing, the current converts the surface of the lead peroxide in the path into the non-conducting oxide, thereby closing the puncture holes and restoring the insulating film.

In its practical form the arrester is built up of a number of cells proportioned to the voltage of the circuit on which it is used. This arrester also is connected to the line through a spark gap arrangement, usually a combination of sphere gap and horn gap.

The oxide film arrester has been extensively used and has proved quite satisfactory. For lower voltage systems such as power distribution circuits, where the cost of the arrester is an important item, a pellet type of oxide film arrester has been developed, the material of which consists of lead peroxide pellets coated with a film of insulating lead oxide powder as a spacer. A high voltage discharge breaking down these films divides among a number of paths through the pellets. Recovery of the insulating coating occurs at the contact surfaces where the current passes.

The "Autovalve" Arrester

The "autovalve" arrester, as its name implies, is another of the valve type arresters. In its newer form the arrester element is a composite of a porous non-conducting material and finely divided conducting material. Between the conducting particles of the material, minute air gaps occur. The composite material is practically an insulator until sufficient volt-

age is impressed upon it to cause breakdown of the minute air gaps, in which event, due to its structure, numerous separate discharge paths are set up, but without sufficient current concentration or local heating in any path to cause an arc. In the absence of arcs a considerable voltage is required to force the current through the material. Therefore when the voltage is reduced, the discharge across the small gaps in the material can no longer be maintained, and the current practically ceases. The small remaining current is readily interrupted by a main series spark gap.

The individual blocks of the autovalve material as now used are rated at 3000 volts each, the arrester being built up of different numbers of blocks according to the line voltage.

The "Thyrite" Arrester

In the "thyrite" arrester the element in series with the spark gap consists of a specially prepared material, which instead of containing within itself discontinuities in different conducting paths, is a substantially homogeneous conductor which has the property that its resistance to large voltages is very much less than to small voltages. Thyrite is a molded material, the composition and characteristics of which may be varied considerably, but in one particular form the current increases 12.6 times when the impressed voltage is doubled. A disk of this material 6″ in diameter and ¾″ thick, will pass one ampere of current when subjected to 580 volts, 12.6 amperes when subjected to 1160 volts, and over 150 amperes when subjected to 2300 volts. It can readily be seen that an arrester of such material will pass only a very small current at normal circuit voltage, while offering comparatively little resistance to high over-voltages.

In its commercial form this arrester is built up of units rated at 11,500 volts, each unit consisting of a stack of 11 disks, the number of such units in the complete arrester being determined

by the line voltage. The arrester is connected to the line through a spark gap.

The "Crystal Valve" Arrester

Another lightning arrester, used chiefly on power circuits not exceeding 30,000 volts, is the "crystal valve" which resembles somewhat the autovalve and thyrite arresters in respect to operation. In this case, however, the arrester is not built up of blocks or unit groups of blocks, but the special material is all in one piece, the dimensions of which are determined by the voltage rating of the arrester. Each arrester contains a series multi-spark gap element.

Other arresters of the valve type have been developed, but the above is thought to include those in most common use. It should be stated that in addition to the lightning arrester proper, it was formerly customary to provide choke coils ahead of the apparatus to be protected, the object of these coils being to help divert the surges away from the apparatus and towards the arresters. Most engineers however now question the utility of choke coils for this purpose and although many such coils are still in use, they are no longer generally employed in new installations. The use of series air gaps and, in some cases, series resistances, has been referred to, but it may not be appreciated that a spark gap, which would seem to be a very simple thing, may be in practice a large, complicated, and expensive device.

The foregoing scarcely more than hints at the enormous amount of time, effort, and expense which have been devoted to the development of lightning arresters. The modern arresters resulting from this effort represent a great advance in effectiveness of protection against lightning, but it must be remembered that the influence of a single arrester extends only over a limited area. While arresters have been simplified in design and reduced in cost, it is still true that the expense of providing them, even for merely limiting failure of equipment,

is an important item. Many more arresters and a much larger expense would be required if an attempt were made to protect all parts of a power system against surges which may cause faults or trip-outs. The number of arresters to be employed in any specific situation is an economic question and has to be determined in accordance with the circumstances prevailing.

Conclusion

In conclusion it is again emphasized that in many respects and to a large extent, lightning is still a mystery. Both electrically and meteorologically it is unique. The ratio of surmise to knowledge about it is high. The practical questions of protecting structures and electrical systems against damage by lightning are better understood than are the theoretical features. While nature is being forced slowly but surely to yield up her secrets, there will probably be many decades of further study and investigation before a satisfactory understanding of lightning as a physical phenomenon is attained.

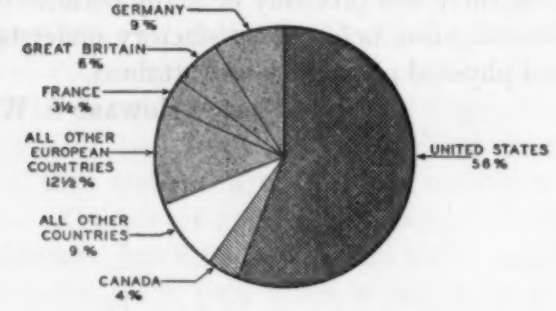
Howard S. Warren

World's Telephone Statistics

January 1, 1932

THE usual annual survey of the world's telephones was completed recently by the Chief Statistician's Division of the American Telephone and Telegraph Company. According to this latest survey, the total number of telephones in the world as of January 1, 1932, was 35,057,669. At that date the United States had 19,690,187 telephones, or about 56.2 per cent of the world's total. Europe had 10,871,581 telephones, representing 31 per cent of the total number in the world.

DISTRIBUTION OF THE WORLD'S TELEPHONES
January 1, 1932



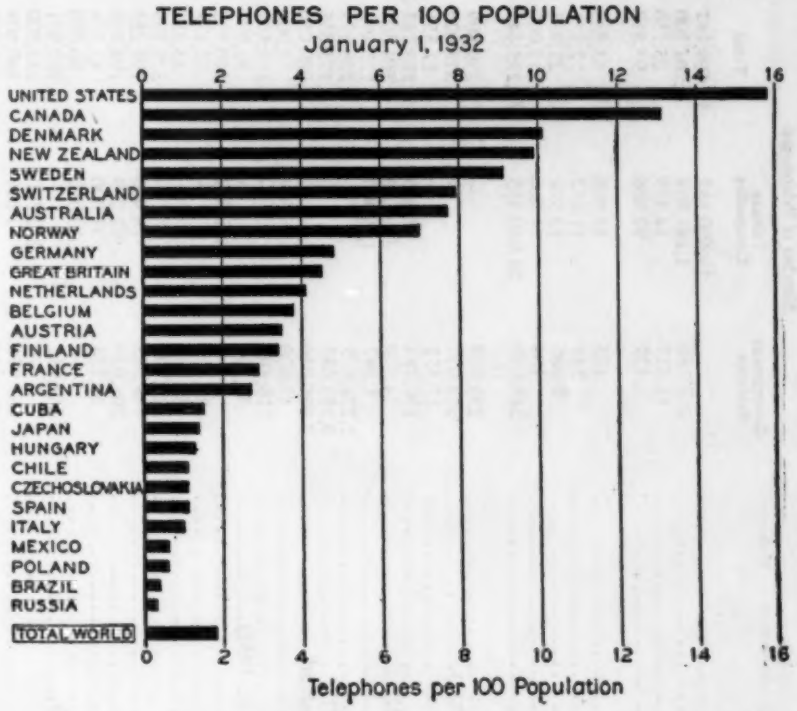
The remaining 4,495,901 telephones, or about 12.8 per cent, were distributed among the countries of Asia, Africa, Oceania and the Western Hemisphere outside of the United States.

The results of the survey have been issued in an eight page pamphlet entitled "Telephone and Telegraph Statistics of the World, January 1, 1932"; and the accompanying tables and charts have been reproduced from this document.

Comparative Telephone Development of Countries

The United States, with a development of 15.8 telephones

per 100 inhabitants, maintained its position of preeminence among the countries of the world in respect of the extent of telephone facilities in relation to population. Canada was second, with a development of 13.1 stations per 100 population. Then follow in order, Denmark with 10.1, New Zealand with 9.9, and Sweden with 9.1 telephones per 100 population, respectively. It is interesting to note that private operation of the telephone service predominates in the three leading



countries from the standpoint of facilities for oral communication by wire. In the United States all telephones are privately owned, while in Canada and in Denmark, private companies operate respectively 84 per cent and 96 per cent of the total instruments in service. Of the major European countries, Germany had a development of 4.8 telephones per 100 inhabitants—less than one-third that of the United States.

TELEPHONE DEVELOPMENT OF THE WORLD, BY COUNTRIES

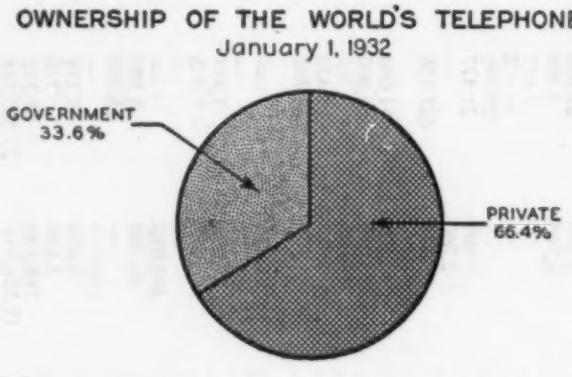
January 1, 1932

Countries	Number of Telephones			Percent of Total World	Telephones Per 100 Population
	Government Systems	Private Companies	Total		
NORTH AMERICA:					
United States		19,690,187	19,690,187	56.17%	15.8
Canada	223,186	1,141,014	1,364,200	3.89%	13.1
Central America	11,317	14,439	25,756	.07%	0.4
Mexico	1,427	92,086	93,513	.27%	0.6
West Indies:*					
Cuba	485	55,098	55,583	.16%	1.5
Porto Rico	589	11,662	12,251	.04%	0.8
Other W. I. Places *	7,985	13,970	21,955	.06%	0.3
Other No. Am. Places *	100	11,900	12,000	.03%	3.3
Total	245,089	21,030,356	21,275,445	60.69%	12.5
EUROPE:					
Austria	239,809	—	239,809	.69%	3.5
Belgium (February 29, 1932)	313,022	—	313,022	.89%	3.8
Bulgaria	17,551	—	17,551	.05%	0.3
Czechoslovakia	150,284	18,859	169,143	.48%	1.1
Denmark (March 31, 1932)	14,899	349,609	364,508	1.04%	10.1
Finland	1,597	125,900	127,497	.36%	3.4
France	1,228,879	—	1,228,879	3.51%	2.9
Germany (March 31, 1932)	3,113,655	—	3,113,655	8.88%	4.8
Great Britain and No. Ireland	2,080,056	—	2,080,056	5.93%	4.5
Greece *	13,000	—	13,000	.04%	0.2
Hungary	116,597	—	116,597	.33%	1.3
Irish Free State (March 31, 1932)	31,994	—	31,994	.09%	1.1
Italy (June 30, 1931)	—	440,392	440,392	1.26%	1.0
Jugo-Slavia	37,488	—	37,488	.11%	0.3
Latvia (March 31, 1932)	53,883	—	53,883	.15%	2.8
Netherlands	325,799	—	325,799	.93%	4.1
Norway (June 30, 1931)	118,355	78,900	197,255	.56%	7.0
Poland	101,939	92,209	194,148	.55%	0.6
Portugal	10,754	31,000	41,754	.12%	0.6
Roumania	—	50,050	50,050	.14%	0.3
Russia† (October 1, 1931)	462,931	—	462,931	1.32%	0.3
Spain	—	252,500	252,500	.72%	1.1
Sweden	558,956	1,649	560,605	1.60%	9.1
Switzerland	324,088	—	324,088	.93%	7.9
Other Places in Europe*	100,520	14,457	114,977	.33%	1.4
Total	9,416,056	1,455,525	10,871,581	31.01%	2.0

SOUTH AMERICA:					
Argentina*	—	313,598	313,598	.90%	2.7
Bolivia	—	2,093	2,093	.01%	0.1
Brazil*	680	165,024	165,704	.47%	0.4
Chile	—	48,130	48,130	.14%	1.1
Colombia*	2,500	27,000	29,500	.08%	0.3
Ecuador	2,968	3,300	6,268	.02%	0.3
Paraguay	—	2,931	2,931	.01%	0.3
Peru	—	14,632	14,632	.04%	0.2
Uruguay	—	29,691	29,691	.08%	1.5
Venezuela	606	21,577	22,183	.06%	0.7
Other So. Am. Places*	2,760	—	2,760	.01%	0.5
Total	9,514	627,976	637,490	1.82%	0.7
ASIA:					
British India*	20,500	34,000	54,500	.16%	0.02
China*	85,000	65,000	150,000	.43%	0.03
Japan (March 31, 1932)	919,605	—	919,605	2.62%	1.4
Other Places in Asia	116,016	15,332	131,348	.37%	0.1
Total	1,141,121	114,332	1,255,453	3.58%	0.1
AFRICA:					
Egypt	44,440	—	44,440	.13%	0.2
Union of South Africa§	113,122	—	113,122	.32%	1.4
Other Places in Africa*	93,176	1,335	94,511	.27%	0.1
Total	250,738	1,335	252,073	.72%	0.2
OCEANIA:					
Australia (June 30, 1931)	498,055	—	498,055	1.42%	7.7
Dutch East Indies	46,104	4,250	50,354	.14%	0.1
Hawaii	—	25,789	25,789	.07%	6.5
New Zealand§	160,779	—	160,779	.46%	9.9
Philippine Islands	6,000*	20,414	26,414	.08%	0.2
Other Places in Oceania*	3,458	778	4,236	.01%	0.2
Total	714,396	51,231	765,627	2.18%	0.9
TOTAL WORLD	11,776,914	23,280,755	35,057,669‡	100.00%	1.8

* Partly estimated.
† U. S. S. R., including Siberia and Associated Republics.
‡ Includes approximately 12,500,000 automatic or "Dial" telephones, of which more than 50% are in the United States.
§ March 31, 1932.

Great Britain had a development of 4.5 and France 2.9 telephones per 100 population. In each of these three countries, the telephone service is operated by the respective Governments. The development of Argentina, 2.7 telephones per 100 population, though very low as compared with that of the United States, is considerably higher than the development of the next highest South American country, namely, Uruguay, which had 1.5 instruments per 100 population. In Asia the majority of the telephones are concentrated in Japan; but even so the Japanese had only 1.4 telephones per 100 inhabitants. The accompanying chart, "Telephones per 100 Popu-



lation," indicates the relative positions of the principal countries of the world as regards telephone density.

Telephones in Large and Small Communities

One fact clearly brought out by the annual survey is that in the United States ample telephone facilities are provided not only in the more densely populated urban centers, but in the less populated sections as well. Thus, referring to the table "Telephone Development of Large and Small Communities," it will be noted that the development of 11.8 telephones per 100 inhabitants in communities of less than 50,000 population in the United States is considerably higher than the total

TELEPHONE DEVELOPMENT OF LARGE AND SMALL COMMUNITIES
January 1, 1932

Country	Service Operated by (See Note)	Number of Telephones		Telephones per 100 Population	
		In Communities of 50,000 Population and Over	In Communities of less than 50,000 Population	In Communities of 50,000 Population and Over	In Communities of less than 50,000 Population
Australia (June 30, 1931)*	G.	284,000	214,055	8.6	6.7
Austria (January 1, 1931)	G.	176,153	57,759	7.5	1.3
Belgium (January 1, 1931)	G.	203,106	89,527	6.1	1.9
Canada	P. G.	732,000	632,200	22.8	8.8
Czechoslovakia	P. G.	66,217	102,926	4.0	0.8
Denmark	P. G.	165,662	196,298	18.0	7.3
Finland	P. G.	49,130	78,367	10.6	2.4
France	G.	715,663	513,216	7.8	1.6
Germany (March 31, 1932)	G.	2,017,437	1,096,218	7.6	2.8
Great Britain and No. Ireland†	G.	1,507,500	601,900	5.8	2.9
Hungary	G.	88,288	28,309	5.0	0.4
Japan (March 31, 1932)	G.	565,053	354,552	3.5	0.7
Netherlands	G.	210,451	115,348	6.6	2.4
New Zealand (March 31, 1932)	G.	62,459	98,320	11.9	9.0
Norway (June 30, 1931)	P. G.	67,921	129,334	16.9	5.3
Poland	P. G.	116,248	77,900	2.6	0.3
Spain	P.	147,447	105,053	3.4	0.6
Sweden	G.	224,483	336,122	22.2	6.5
Switzerland	G.	143,921	180,167	16.9	5.6
Union of South Africa	G.	60,313	52,752	6.3	0.7
United States	P.	10,976,449	8,713,738	21.9	11.8

Note: P. indicates telephone service operated by private companies, G. by the Government, and P. G. by both private companies and the Government. See first table.

* Partly estimated.

† March 31, 1932.

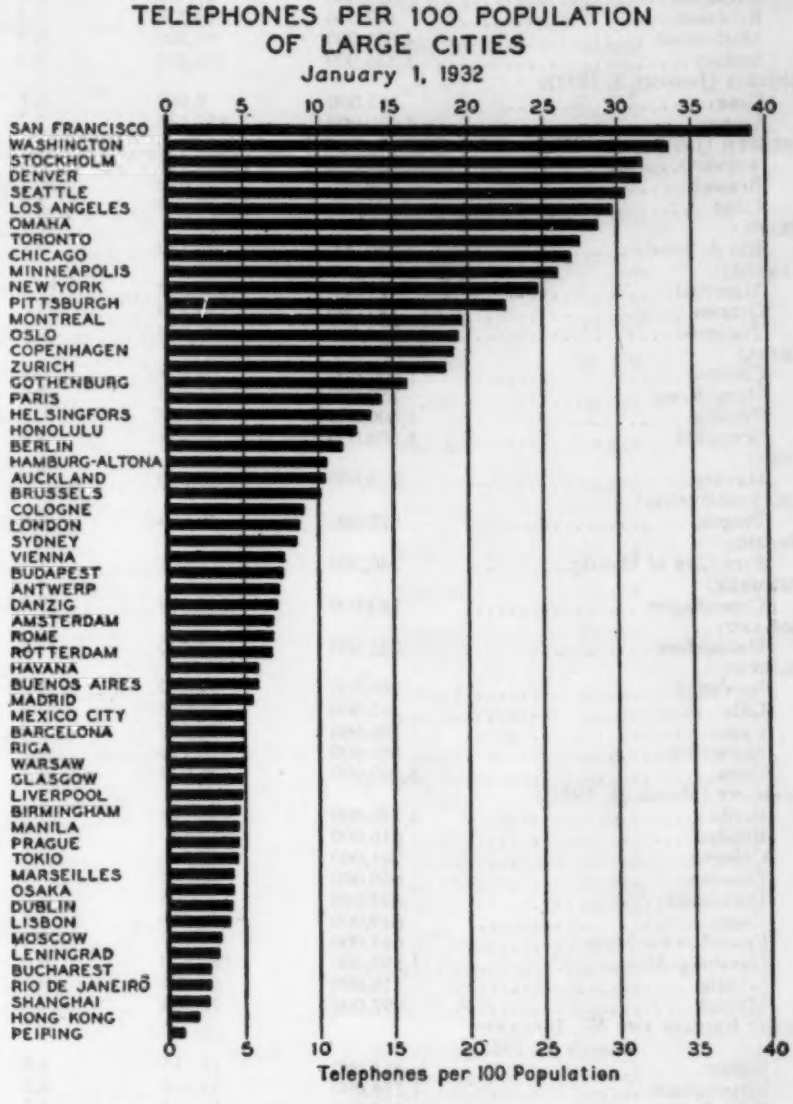
development of all other countries with the single exception of Canada. This relatively high telephone development of less populated regions in the United States becomes all the more striking when it is compared with similar figures for the major European countries. Great Britain, for example, had a development of 2.9 for its less populated sections; the corresponding figure for Germany was 2.8, while in the case of France there were only 1.6 telephones per 100 people in communities of less than 50,000 inhabitants. By comparing these figures with the corresponding development in communities of more than 50,000 population—Great Britain 5.8, Germany 7.6 and France 7.8—it is apparent that the telephone facilities in these foreign countries are concentrated mainly in the cities.

Telephones in Large Cities

The accompanying chart, "Telephones per 100 Population of Large Cities," shows practically no change from the preceding year as regards the relative position of large cities of the world in respect of telephone development. Thus, of the twelve cities heading the list of selected cities, ten are in the United States. Likewise, the capital cities of Paris, Berlin and London continue to be well down on the list, being eighteenth, twenty-first and twenty-sixth, respectively. San Francisco is again the best developed large city in the world, having 39.1 telephones per 100 population. Washington is second with a development of 33.4, and Stockholm is third with 31.7; then follow in order the American cities, Denver, 31.6, Seattle, 30.5, Los Angeles, 29.7 and Omaha, 28.7.

The accompanying table, "Telephone Development of Large Cities," is supplementary to the chart discussed in the previous paragraph and includes a larger number of cities. This table indicates still more emphatically the marked superiority of the American cities over those in foreign countries as regards tele-

phone density. Thus, the total of 51 American cities having 200,000 population and over, representing a combined popula-



tion of 36,995,100, had a development of 22.9. With the exception of Stockholm and the Canadian city of Toronto, this

TELEPHONE DEVELOPMENT OF LARGE CITIES

January 1, 1932

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
ARGENTINA:			
Buenos Aires	2,875,000	170,352	5.9
AUSTRALIA:			
Adelaide	325,000	27,999	8.6
Brisbane	317,000	24,559	7.7
Melbourne	1,031,000	91,305	8.9
Sydney	1,256,000	106,231	8.5
AUSTRIA (January 1, 1931):			
Graz	165,000	9,469	5.7
Vienna	2,020,000	155,128	7.7
BELGIUM (January 1, 1931):			
Antwerp	519,000	37,795	7.3
Brussels	948,000	95,632	10.1
Liège	424,000	20,669	4.9
BRAZIL:			
Rio de Janeiro	1,650,000	45,180	2.7
CANADA:			
Montreal	979,000	192,302	19.6
Ottawa	182,200	39,399	21.6
Toronto	752,700	206,968	27.5
CHINA:			
Canton	1,000,000	4,300	0.4
Hong Kong	750,000	13,463	1.9
Peiping	1,400,000	12,583	0.9
Shanghai	1,500,000	38,428	2.6
CUBA:			
Havana	720,000	42,310	5.9
CZECHOSLOVAKIA:			
Prague	870,000	39,658	4.6
DANZIG:			
Free City of Danzig	240,000	17,161	7.2
DENMARK:			
Copenhagen	780,000	148,378	19.0
FINLAND:			
Helsingfors	255,000	34,426	13.5
FRANCE:			
Bordeaux	268,000	17,679	6.6
Lille	212,000	16,043	7.6
Lyons	596,000	31,527	5.3
Marseilles	682,000	28,716	4.2
Paris	3,000,000	426,024	14.2
GERMANY (March 31, 1932):			
Berlin	4,270,000	496,148	11.6
Breslau	616,000	42,489	6.9
Cologne	741,000	66,768	9.0
Dresden	630,000	60,085	9.5
Dortmund	534,000	24,702	4.6
Essen	649,000	29,726	4.6
Frankfort-on-Main	615,000	64,927	10.6
Hamburg-Altona	1,595,000	169,670	10.6
Leipzig	716,000	67,993	9.5
Munich	697,000	75,784	10.9
GREAT BRITAIN AND NO. IRELAND (March 31, 1932):			
Belfast	415,000	16,717	4.0
Birmingham	1,178,000	53,885	4.6
Bristol	412,000	19.524	4.7
Edinburgh	441,000	29,599	6.7
Glasgow	1,180,000	57,028	4.8
Leeds	508,000	22,488	4.4
Liverpool	1,184,000	56,487	4.8
London	8,900,000	769,928	8.7
Manchester	1,094,000	61,889	5.7
Newcastle	469,000	18,811	4.0
Sheffield	514,000	19,015	3.7
HAWAII:			
Honolulu	140,000	17,516	12.5
HUNGARY:			
Budapest	1,012,000	77,055	7.6
Szeged	136,000	2,381	1.8

TELEPHONE DEVELOPMENT OF LARGE CITIES (Concluded)

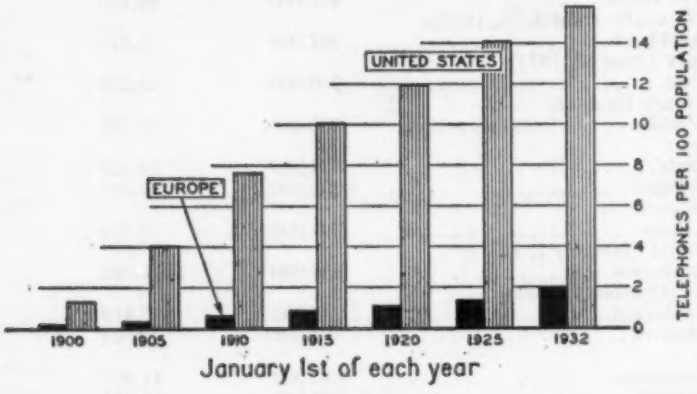
January 1, 1932

Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones per 100 Population
IRISH FREE STATE:			
Dublin (March 31, 1932)	415,000	17,132	4.1
ITALY:			
Genoa	650,000	29,153	4.5
Milan	990,000	78,999	8.0
Rome	945,000	65,173	6.9
JAPAN (March 31, 1932):			
Kobe	804,000	29,849	3.7
Kyoto	977,000	36,729	3.8
Nagoya	934,000	29,238	3.1
Osaka	2,520,000	104,902	4.2
Tokio	3,425,000	155,219	4.5
LATVIA (March 31, 1932):			
Riga	395,000	19,334	4.9
MEXICO:			
Mexico City	1,000,000	50,390	5.0
NETHERLANDS:			
Amsterdam	766,000	52,487	6.9
Haarlem	152,000	11,227	7.4
Rotterdam	605,000	41,096	6.8
The Hague	487,000	46,126	9.5
NEW ZEALAND (March 31, 1932):			
Auckland	207,000	21,579	10.4
NORWAY (June 30, 1931):			
Oslo	250,000	48,524	19.4
PHILIPPINE ISLANDS:			
Manila	385,000	17,631	4.6
POLAND:			
Lodz	824,000	14,330	1.7
Warsaw	1,178,000	57,361	4.9
PORTUGAL:			
Lisbon	595,000	23,318	3.9
ROUMANIA (January 1, 1931):			
Bucharest	630,000	17,103	2.7
RUSSIA (October 1, 1931):			
Leningrad	2,235,000	70,419	3.2
Moscow	2,780,000	90,561	3.3
SPAIN:			
Barcelona	850,000	41,605	4.9
Madrid	850,000	46,851	5.5
SWEDEN:			
Gothenburg	248,000	39,545	15.9
Malmö	130,000	19,419	14.9
Stockholm	436,000	137,999	31.7
SWITZERLAND:			
Basel	148,000	25,456	17.2
Berne	112,000	20,106	18.0
Geneva	144,000	24,079	16.7
Zurich	254,000	46,963	18.5
UNITED STATES:*			
New York	7,100,000	1,753,380	24.7
Chicago	3,488,000	939,481	26.9
Los Angeles	1,345,000	398,861	29.7
Pittsburgh	1,000,000	225,234	22.5
Total 9 cites over 1,000,000 Population	20,827,000	4,988,907	24.0
Milwaukee	737,600	156,408	21.2
San Francisco	665,000	260,204	39.1
Washington	582,500	194,653	33.4
Minneapolis	508,000	131,914	26.0
Total 11 cities with 500,000 to 1,000,000 Population	7,018,900	1,574,916	22.4
Seattle	408,200	124,617	30.5
Denver	293,200	92,547	31.6
Hartford	237,700	58,361	24.5
Omaha	231,200	66,413	28.7
Total 31 cities with 200,000 to 500,000 Population	9,149,200	1,912,794	20.9
Total 51 cities with more than 200,000 Population	36,995,100	8,476,617	22.9

* There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups, and the development of certain representative cities within each of such groups.

average development for 51 American cities exceeds that of any single large foreign city. Chicago had 939,481 telephones, a development of 26.9; New York had 1,753,380 telephones, or 24.7 instruments per 100 of its inhabitants. The number of telephones in Chicago, however, represents less than five per cent of all the telephones in the United States, and New York has less than nine per cent of the total. In the case of the capital cities of London and Paris, however, it will be found

TELEPHONE DEVELOPMENT
IN THE UNITED STATES AND EUROPE



that the number of telephones constitutes a far greater proportion of the total number in the country as a whole. Thus, London, with its 769,928 telephones, had 37 per cent of all the instruments in Great Britain; while Paris, with 426,024 telephones, had 34 per cent of all the instruments in France. Similarly, more than one-fourth of all the telephones in Germany were concentrated in the four cities of Berlin, Hamburg-Altona, Leipzig and Munich.

The comparative telephone development of the United States and Europe at various dates since 1900 is shown on the accompanying chart. It is interesting to note that the telephone development of Europe on January 1, 1932, was approximately the same as that of the United States about thirty years ago.

Notes on Recent Occurrences

OVERSEAS SERVICE EXTENDED TO GUATEMALA, INDIA, NICARAGUA AND S. S. *BERENGARIA*

GUATEMALA, India, Nicaragua and the S. S. *Berengaria* were brought within speaking distance of all Bell and Bell-connecting telephones in the United States, Canada, Cuba and Mexico by recent extensions of overseas telephone service.

An exchange of greetings between government and telephone officials of Guatemala and the United States opened service between those countries on April 17. The cost of a three-minute conversation between New York and Guatemala City is $21. Guatemala is reached by a short-wave radio telephone circuit between stations of the Tropical Radio Telegraph Company at Guatemala City and stations of the American Telephone and Telegraph Company at Miami, linked with the Bell System network.

Regular telephone communication between the United States and Bombay and Poona in India began on May 9 through the co-operation of the American Telephone and Telegraph Company and the British Post Office, linking one of the transatlantic radio telephone channels between the United States and England with a short wave channel connecting London and radio telephone stations near Bombay. A three-minute conversation between New York and Bombay or Poona costs $45, with $15 for each additional minute.

Service between the United States and Nicaragua began on June 7 through the co-operation of the American Telephone and Telegraph Company and the Tropical Radio Telegraph Company. The service was inaugurated by conversations between government officials of the two countries. A three-minute conversation between New York and any point in Nicaragua costs $21, with $7 for each additional minute.

Prime Minister J. Ramsay MacDonald of Great Britain, aboard the steamship *Berengaria* several hundred miles out at sea, inaugurated regular telephone service between the liner and North American telephones on April 20, when he spoke with his country's Ambassador, Sir Ronald Lindsay, who was at the British Embassy at Washington, D. C. The *Berengaria* is the nineteenth liner to have ship-to-shore service with the United States.

PRESENTATION OF THE JOHN J. CARTY MEDAL AND AWARD

WHEN General John J. Carty retired from active service on July 1, 1930, after more than fifty years of service in the Bell System, the Directors of the American Telephone and Telegraph Company established in the National Academy of Sciences a gold medal and award in his honor and bearing his name. At the same time his immediate associates provided the design of the medal and the necessary dies to be used by the United States Mint in striking the medal.

These acts were in recognition of General Carty's outstanding achievements, not only in the field of electrical communication, but likewise in the whole field of applying science to the benefit of mankind.

Under the provisions of the Deed of Gift, the National Academy of Sciences is empowered to make an award not oftener than once in two years, without restriction of race, nationality, sex or field of science, to anyone who in its judgment has done particularly outstanding work in the promotion of scientific research or application. The Deed of Gift also provides that, in addition to the medal, the entire net income from the medal fund since the last preceding award shall be given to the medalist.

Acting under the Deed of Gift, the National Academy of Sciences appointed a Carty Medal Committee, which, in due course, recommended that, in their judgment, no more fitting

candidate could be selected for the first award of the medal than General Carty himself. This recommendation of the Committee was unanimously approved by the National Academy of Sciences last November, and arrangements were made for a presentation of the medal to General Carty at the annual meeting of the Academy in Washington at the end of April, 1933.

General Carty's untimely death in December made necessary a change in these plans, and the Academy then decided to present the medal posthumously. This altered program was carried out, and the medal and award were presented at the annual dinner of the Academy on April 25, 1933. The case for the presentation of the medal to General Carty was stated by Dr. Frank B. Jewett, the presentation was made by Dr. W. W. Campbell, President of the Academy, and the medal and award were received by General Carty's son, Dr. John R. Carty, on behalf of his mother, whose health did not permit her to be present. A replica of the medal in bronze is in the Historical Museum in the Headquarters Building of the American Telephone and Telegraph Company.

MESSRS. GHERARDI AND IVES ELECTED TO NATIONAL ACADEMY OF SCIENCES

AT THE annual business meeting of the National Academy of Sciences in Washington on April 26, 1933, Mr. Bancroft Gherardi, Vice President and Chief Engineer of the American Telephone and Telegraph Company, and Dr. Herbert E. Ives of Bell Telephone Laboratories, were elected to membership. Mr. Gherardi was proposed by the Section of Engineering and Dr. Ives by the Section of Physics. With their election, the Bell System is now represented in the Academy by four men, Dr. Jewett and Dr. Davisson of Bell Telephone Laboratories already being members of the Academy. The late General J. J. Carty was also a member of the Academy.

The National Academy of Sciences was established by act of Congress during President Lincoln's administration, and is the

only nationally chartered scientific organization in the United States. Its present membership of about 250 comprises leaders from all fields of pure and applied science. By statutory limitation, not more than fifteen men or women can be elected to membership in any one year.

ACADEMIC HONORS FOR BELL SYSTEM MEN

BANCROFT GHERARDI, Vice President and Chief Engineer of the American Telephone and Telegraph Company, has received the honorary degree of Doctor of Engineering from the Polytechnic Institute of Brooklyn, New York.

William H. Meese, Vice President and Works Manager of the Western Electric Company's Point Breeze Works at Baltimore, has received the honorary degree of Doctor of Laws from Washington College, Chestertown, Maryland.